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Use of Composite Pipe Materials in the Transportation of Natural Gas

Patrick Laney

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Idaho National Engineering and Environmental Laboratory
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Prepared by: Patrick Laney
Idaho National Engineering and Environmental Laboratory
Idaho Falls, Idaho

With Contributions From: Ian Kopp
Kenway Corporation
Augusta, Maine

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Idaho National Engineering and Environmental Laboratory
Fossil Energy Technologies Department
Idaho Falls, Idaho 83415

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ABSTRACT

The objective of this study is to evaluate current and potential use of composite pipe in the natural gas pipeline industry. This investigation addresses primary factors affecting research, development, and deployment of commercially viable composite materials for gas and petroleum pipeline applications, including but not limited to gathering, transmission and distribution systems. The investigation concentrated on the pipe aspects, and does not address valves or other ancillary hardware associated with these types of pipelines. The application of composite pipe in natural gas service is governed by both technical and regulatory requirements. Consequently, the study attempted to identify both sets of requirements to establish the framework in which to assess current use of composite pipe and research issues that must be addressed to expand the range of application. An in-depth, but not exhaustive search and review of the regulations, both state and federal was conducted. Current research related to application of composite pipe in natural gas pipeline service is summarized. Technical barriers to broader application are identified. All of the relevant safety regulations were reviewed at the federal level. This investigation did not include any analysis of offshore use of composite pipe.

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ACRONYMS

ABS	Acrylonitrile-Butadiene-Styrene
AGI	American Gas Institute
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CRLP	Composite Reinforced Line Pipe
FRP	Fiberglass Reinforced Plastic
FRP	Fiberglass Reinforced Pipe
FRP	Filament Reinforced Plastic (Pultrusion Process)
GRE	Glass Reinforced Epoxy
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
MACT	Maximum Achievable Control Technology
MDPE	Medium Density Polyethylene
NDE	Non Destructive Examination
NESHAP	National Emission Standard for Hazardous Airborne Pollutants
NFPA	National Fire Protection Association
NTSB	National Transportation Safety Board
OD	Outside Diameter
RTP	Reinforced Thermosetting Plastic
RTRP	Reinforced-Thermosetting-Resin-Pipe
RPMP	Reinforced Polymer Mortar Pipe
USC	United States Code

1. INTRODUCTION

The objective of this study is to evaluate current and potential use of composite pipe in the natural gas pipeline industry. Because of the similarity in applications between natural gas and some parts of the petroleum production system, applications in the petroleum industry were also reviewed. This investigation addresses primary factors affecting research, development, and deployment of commercially viable composite materials for gas and petroleum pipeline applications, including but not limited to gathering, transmission and distribution systems. The overall objective is to look at composite pipe use in the natural gas industry in general. However this investigation spent considerable time looking at a particular type of composite pipe, specifically Reinforced Thermosetting Resin Pipe (RTRP). This material often referred to as fiberglass pipe (other fibers besides glass are also used) is the main focus of the Kenway Corporation business and therefore their area of expertise. This investigation concentrated on the pipe aspects, and does not discuss valves or other ancillary hardware associated with these types of pipelines. The application of composite pipe in natural gas service is governed by both technical and regulatory requirements. Consequently, the study attempted to identify both sets of requirements to establish the framework in which to assess current use of composite pipe and research issues that must be addressed to expand the range of application. It is beyond the scope of this investigation to list all of the technical requirements for pipe used in natural gas transportation. They are found in approximately 30 different standards, test methods, specifications and recommended practices cited in the federal regulations. In addition, states and municipalities can specify additional technical requirements for natural gas transportation under their jurisdiction. An in-depth, but not exhaustive search and review of the regulations, both state and federal was conducted. It was beyond the scope of this investigation to do a complete detailed analysis of the state and federal regulations that affect every aspect of composite pipe use in the petroleum industry. However all of the relevant safety regulations were reviewed at the federal level. An attempt was made to determine the basic natural gas pipeline regulation in each of the 50 states. An Internet search of each states' official web site(s) was conducted, searching for information on pipeline regulation and safety. This investigation did not include any analysis of offshore use of composite pipe.

Thousands of miles of new natural gas pipeline are put in service each year while thousands more miles of deteriorated natural gas pipeline are replaced. Composite pipe materials in the oilfields are accepted and widely used. Low to moderate pressure composite and plastic flowline and gathering line systems for oil and natural gas have been in service for many years. Plastics are the pipe of choice for low-pressure distribution lines. While composites and plastics have been used for flowlines, gathering lines and distribution lines, they have yet to be accepted in high-pressure natural gas transmission systems. There has however been limited testing of a steel/composite hybrid in a natural gas transmission pipeline application. Results of this investigation indicate there are a number or barriers that need to be overcome to make large diameter composite pipe a viable alternative for high-pressure natural gas transportation in the future. There is a need for R&D in the areas of materials science of resins and fibers; combinations of composites and traditional materials; manufacture of continuous lengths of RTRP composite pipe; on site coating or overlay of steel pipe with a composite material; armoring or coating RTRP pipe; material failure through delamination; joint failure and automated quality control systems. The goal of any future research should not be to make composites equal to steel pipe, but to make composites the pipe material of choice for high-pressure large diameter natural gas transmission pipelines.

2. NATURAL GAS INDUSTRY OVERVIEW

Following World War II, the natural gas industry grew at a very aggressive rate. The 40-year period between 1948 and 1999 saw about 570,000 miles of transmission pipeline capability being built. As of 1998 there were more than 532,000 miles of natural gas pipelines, with almost half in North America.[1] Not a month goes by without announcements of new natural gas pipelines being planned somewhere in the world. Recent studies by industry experts indicate the demand for new natural gas pipelines will continue to grow in spite of the recent downturn in the in the petroleum industry, and the flat or declining prices being paid for natural gas. Overall demand for natural gas is predicted to increase about 2% per year through 2020, with the majority of the increase going to electrical generation capacity.[2] Gas transmission pipeline construction of all diameters worldwide, due to be completed in the next 2-3 years is estimated to be about 37,000 miles. Of that total, approximately 8,000 miles is planned for North America (4,300 United States, 3,700 Canada). In the U.S. 4-10 in. pipelines are predicted to account for approximately 0.2% of that total; 12-20 in. pipe will be approximately 4%; 22-30 in. pipe will be approximately 40%; and new >32 in. pipelines account for the remaining 56%.[2] Another recent estimate is that “by 2015 some 43,000 mi of pipeline additions will be required to satisfy an expanding market.”[3] Other estimates for North America predict more than 50,000 miles of new transmission pipeline being built in the 2001-2010 timeframe at a cost of over $80 billion.[1] The challenge to the pipeline industry is to meet the increased worldwide demand while reducing the cost. The US Energy Information Agency predicts that the price of natural gas on the average will be in the $3 to $4 range through 2020. In order to meet the delivery demands and overcome the flat price, the pipeline industry will have to come up with innovative methods to transport natural gas from wellhead to household and commercial users.

Experts in the industry are all in agreement that future transmission pipelines will have to operate at higher pressures. In order to meet the increased demands, maintain safety and reliability, and be competitive, pipeline designers and operators are looking at alternatives to conventional steel pipe. Advancements in bonding techniques have lead to the use of Composite Reinforced Line Pipe (CRLP), a patented process that applies glass-resin reinforcement to steel pipe to form an outer protective barrier with additional hoop strength. The use of steel pipe with a composite overwrap together make a new type of pipe that has exceptional strength characteristics with positive advantages in weight and corrosion control. A 2 Km 24-inch OD section of CRLP pipe developed by NCF Industries was installed in the winter of 2001 and is being tested by TransCanada Pipelines in north-western Canada.[4] The next engineering step in the transmission industry is to go to total composite pipe for natural gas transmission.

3. NATURAL GAS SYSTEM DESCRIPTION

In order to understand both the technical and regulatory requirements of the natural gas transportation system in the United States, it is first necessary to understand the various components or subsystems that form the network. This investigation looked at regulations and requirements for pipe used in natural gas gathering, transmission and distribution systems. In researching the regulations and definitions, there appears to be one more pipeline system that is not clearly addressed in the regulations. The general term for this system in the industry is "flowlines". The generally accepted definitions for the various natural gas transportation subsystems are summarized below. Most come from the Code of Federal Regulations Title 49 Transportation, Part 192 Transportation of Natural Gas and Other Gas By Pipeline: Minimum Safety Standards. For more detailed definitions of the terms presented below, please refer to Appendix A - Definitions.

In most instances, natural gas transportation from the wellhead to the final customer is accomplished through four major pipeline systems of widely varying physical sizes and pressure capacities. From the wellhead, the gas enters **flowlines**, which carry the gas to **gathering lines**. From the gathering lines the product is moved into larger diameter, generally higher pressure **transmission lines** for long distance transmission. When the gas is delivered to the final customer, be it a commercial or residential entity, it is delivered through **distribution lines**. It's important to note however, that in some cases natural gas is delivered directly from gathering lines to agricultural, residential, commercial or industrial end users.

The definition of **gathering systems** is quite complex in the federal regulations. In defining a Gathering System, the CFR's cite the 53 page American Petroleum Institute "(API) Recommended Practice 80, Definition of Onshore Gathering Line" [5] for a definition that includes 11 subparts. In this report, when we refer to a gathering system it will be in the more general industry term, which is, the pipeline system used to transport gas from the endpoint of a production operation (treatment, separation, or compression facilities) to the point where gas first enters a transmission/distribution system.

In the federal regulations, a **transmission system / transmission line** is defined as a pipeline, other than a gathering line. For the purposes of this investigation, we will define a transmission system as pipelines installed for the purpose of transmitting gas from a source or sources of supply to one or more distribution centers, or city gates, to one or more large volume customers, or a pipeline installed to interconnect sources of supply. Transmission lines generally operate at higher pressures, above 800 psi, and extend over longer distances.[6]

According to the CFR 49 Part 192, a **distribution line / distribution system** is defined as a pipeline other than a gathering or transmission line. For the purpose of this investigation, we will define a distribution system as "The gas distribution piping system that delivers gas from the transmission system (or city gate) to the customer meter. Distribution piping systems consist of mains and services. A "main" is a pipe installed in a community to convey gas to individual service lines. A "service line" is the piping installed between a main or other source of supply, and the customer meter set assembly." [6]

In addition to the very specific definitions for the various transmission systems, the regulations have specific definitions for the pipe that carries the gas. The CFR defines pipe as any pipe or tubing used in the transportation of gas, including pipe-type holders, and pipelines as all parts of those physical facilities through which gas moves in transportation, including pipe, valves, and other appurtenance attached to pipe, compressor units, metering stations, regulator stations, delivery stations, holders, and fabricated assemblies.

4. COMPOSITE MATERIALS

This investigation has focused on composite pipe. Initially it was assumed that "composites" meant fiberglass composites. It was quickly evident that it is hard to draw the line when defining "composite pipe". Is it resin and reinforcing materials like fiberglass? Is it steel pipe with a composite material wrapped on the outside? Is it steel pipe with a composite liner? Is it a plastic liner with a reinforcing wrap on the outside? Is it plastic with reinforcing materials included in the matrix? All of these are used in the transportation of natural gas. All are considered composites in the industry. A cursory review of the literature reveals that "composites" is a term that has varying meanings among engineers and manufacturers. In the most general of definitions, a composite consists of "Two or more dissimilar materials which when combined are stronger than the individual materials." [7] This general definition covers the various types of pipe currently being used in the transmission of natural gas which includes metal, plastic, and thermosetting resin pipe as well as various combinations of these three types. A more precise definition for thermosetting composites would be "a combination of a reinforcement fiber in a thermoset polymer resin matrix, where the reinforcement has an aspect ratio that enables the transfer of loads between fibers, and the fibers are chemically bonded to the resin matrix." [7] Characteristics of composites that make them ideal candidates for natural gas transmission include resistance to chemical and cathodic corrosion, high strength, light weight, and flexibility. Generally speaking, composites have a higher strength-to-weight ratio that steel. With the ability to control the type, amount and direction of application of the reinforcement material, composite pipe becomes an ideal candidate for widely varying pressure applications.

Fiberglass composites have been used in the petroleum industry for transportation of natural gas for a long time. However, they have not been used in high volume high-pressure natural gas transmission applications in any significant way. There are a number of different resins and fiber reinforcement materials used in composite pipe manufactured today. Glass fiber is the most prevalent reinforcement material, used in over 90% of all resin/filament composites manufactured today. The most prevalent resins and reinforcement material types used today are described below: [8]

4.1 Resin

- General purpose polyester resins – classified as orthophthalic polyesters, wide range of use in the fiberglass reinforced plastic (FRP) industry, has moderate strength and corrosion resistance, cures at room temperature, lowest cost

- Improved polyester resin – classified as isophthalic polyesters, good strength and corrosion resistance, also widely used in FRP corrosion applications, room temperature cure, slightly more expensive than general purpose polyester resins

- Vinyl ester resin – a chemical combination of epoxy and polyester technology, very good corrosion resistance, superior strength and toughness properties, higher cost, widely used as corrosion liner in FRP products

- Bisphenol-A Fumarate, chlorendic resins – exotic system for improved corrosion resistance in harsh environments, have a higher temperature capability, higher cost resins, used widely in the paper and pulp industry

- Phenolic resins – excellent flammability properties including flame retardance and low smoke emissivity, lower elongation, moderate strength, higher cost, applications include oilfield piping and fire resistant systems structures

- Epoxy resins – many types available, best strength properties, generally heat-cure required, good chemical resistance, higher viscosity systems, higher material cost, broad range of applications including oilfield piping and tanks

4.2 Reinforcement Material

- E-Glass – a good strength, low modulus, lowest cost fiber, available in many forms, commonly used in commercial and industrial products, most-used in filament winding (pipe manufacture)

- S-Glass – better strength than E-Glass, higher modulus, higher cost fiber, commonly used in aerospace and high performance pressure vessel applications

- Aramid – good strength, higher modulus, higher cost fiber, very low density (one-half of glass fiber), excellent impact and damage tolerance properties, poor compression and shear strength (Dupont KEVLAR ™ falls in this category)

- Carbon/Graphite – a wide strength range, highest modulus, intermediate density (two-thirds of glass fiber), poor impact or damage tolerance, best tensile strength and stiffness properties with the highest cost of all the fibers

Fiberglass pipe also has very specific definitions in the regulations and standards. It is defined in the ASTM standards as a "tubular product containing glass fiber reinforcements embedded in or surrounded by cured thermosetting resin." [9] The two most common types of fiberglass pipe are reinforced-thermosetting-resin-pipe (RTRP) and glass-fiber-reinforced polymer mortar pipe (RPMP) which is a type of fiberglass pipe with aggregate added to the matrix. In the oil industry, fiberglass pipe is also commonly referred to as Fiberglass Reinforced Plastic (FRP), or Glass Reinforced Epoxy (GRE). More detailed explanations and definitions are provided in Appendix A.

Fiberglass pipe is generally made by one of two methods, filament winding or centrifugal casting. Filament winding can be done by hand or by a machine process. ASTM D 2996 defines filament winding as "a process used to manufacture tubular goods by winding continuous fibrous glass strand roving, or roving tape, saturated with liquid resin or preimpregnated with partially cured resin onto the outside of a mandrel in a predetermined pattern under controlled tension."[10] With the filament winding process, the inside diameter of the pipe is constant, while the outside diameter varies with the amount of resin and reinforcement material wound on the mandrel. Centrifugal casting is a pipe manufacturing process that applies resin and reinforcement material to the inside of a mold that is rotated and usually heated. During this process the resin is polymerized and a pipe is formed. Using the centrifugal casting method the inner diameter of the pipe can vary with the amount of resin and reinforcement material used, while the outside diameter is constant. Fiberglass pipe can also be contact molded (ASTM D6041). While this method produces a high quality pipe it is labor intensive and not cost competitive.

Composite Reinforced Line Pipe (CRLP) is a type of pipe which consists of steel pipe coated or wrapped in a continuous composite shell material that adds strength and protection to the steel. CRLP is relatively new and has not been specifically defined in the ASTM standards.

Another relatively new type of composite pipe used in the transportation of natural gas is glass reinforced epoxy laminate pipe such as the Fiberspar Line Pipe™. The Fiberspar Line Pipe™ is being widely used in flowline applications. This pipe currently comes in diameters from 1-1/4 to 4 inches and pressure ratings from 750 to 3000 psi. The unique feature of this composite pipe is that it is spoolable and comes in lengths up to 6 miles long.

While Polyethylene pipe is not considered as a composite, it is important to mention in this investigation, as it is a major component of natural gas distribution systems. Polyethylene is a linear polymer prepared from ethylene that can be formed in high, medium or low-density versions and is particularly easy to mold when forming. This material is easy to form into pipe that is light, tough, chemical resistant and can be spooled. HDPE is used in the transportation of natural gas both in distribution lines, and flowlines, as well as some new applications as a composite with steel and fiber products.

5. THE REGULATORY FRAMEWORK

A major overhaul of gas transmission regulations in the United States is on the horizon. Concerns over safety and the environment, new materials technology and the desire of industry to transport natural gas at higher pressures have made changes necessary. Congress is looking at a number of proposals and options from the Office of Pipeline Safety, and industry sources. The following statement was issued by the National transportation Safety Board (NTSB) Chairman, Jim Hall on August 24, 2000 following a visit to a gas pipeline accident scene near Carlsbad New Mexico where 11 people were killed.

> *National Transportation Safety Board investigators thus far have determined that the section of pipe that failed during this accident was originally installed in 1952. It is unfortunate that this pipe had never been inspected with an internal inspection tool or hydrostatically tested in all that time. There are no federal regulations requiring such tests. Although this section of pipeline as configured could not accommodate an internal inspection tool, it could have been pressure tested or examined by other means. The NTSB has been urging mandatory testing requirements such as internal inspections and pressure tests since 1987. No American would want to use any transportation vehicle that would not be properly inspected for 48 years, nor should we have pipelines traveling though any of our communities in this condition. The Safety Board's investigation continues. We hope to find out why this pipeline failed and what additional steps might be recommended to prevent such accidents in the future.*

It is not clear at this time what the long-term ramifications of new legislation will be. Much of the current legislative discussion is on testing, reliability and certification of existing pipelines. Certainly there will be increased demand for research and development in the natural gas transportation industry as a result of new legislation. Whether it will focus on maintenance and inspection or on new materials remains to be seen.

The natural gas system is somewhat unique in that it is governed by a complex combination of federal, state, and local regulations depending on the specific subsystem and application. Because of this it is difficult to establish a single set of requirements even for the subsystems that industry can use to in identifying product specifications for new applications. Identified below are some of the key regulations governing the use of composite pipe in natural gas service.

5.1 Federal Regulations

Natural gas transmission at the federal level is regulated by the rules and regulations put forth in the United States Code, specifically Title 49 – Transportation. In the federal regulations, transportation of gas is defined as gathering, transmission, or distribution of gas by pipeline, or the storage of gas, in interstate or foreign commerce (for a detailed definition see **Appendix B**). As pointed out in the discussion above, regulation of gathering lines is a complex issue. According to the federal regulations, the Secretary will consider factors such as the length of the line from the well head, the location, operating pressure, diameter, throughput and composition of the gas before determining if it should be a regulated gathering line. In the federal regulations the Secretary of Transportation is given authority to set minimum safety standards for pipeline transportation and for pipeline facilities. In these regulations there is a clear distinction between interstate and intrastate natural gas transmission. An intrastate gas pipeline facility (pipeline, right-of-way, facilities, buildings and equipment used to transport natural gas) is not subject to the jurisdiction of the Federal Energy Regulatory Commission under the Natural Gas Act if it meets certain minimum safety standards and is regulated by the state. Interstate pipeline facilities however, are subject to jurisdiction of the Commission.

Under section 49 of the Code of Federal Regulations, there are eight parts (190 – 195 and 198 - 199) that specifically address the transmission of natural gas. Part 192 "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards" is the foundation of the natural gas transmission rules and regulations in the US. and provides references and details on materials for pipeline construction. A brief description of parts 190, 191, 193, 194, 195, 198, and 199 can be found in **Appendix B**.

Part 192 either defines or references standards that set pressure, temperature and wall thickness limitations for steel and plastic pipelines. Part 192 "incorporates by reference" approximately 30 American Gas Association (AGA), American Petroleum Institute (API), American Society of Testing Materials (ASTM), American Society of Mechanical Engineers (ASME), National Fire Protection Association (NFPA) and American National Standards Institute (ANSI) procedures, test methods, recommended practices and specifications. Part 192 also has an appendix on "Qualification of Pipe" that cites an additional 10 API and ASTM specifications for pipe used in natural gas transmission applications.

If FRP pipe is used in high-pressure interstate transmission of natural gas, amendments to 49 CFR 192 will undoubtedly be required. Some of the more recent amendments to this regulation allow companies to employ lower cost, new technologies (e.g. composites) to conduct repairs on high-pressure steel transmission/distribution pipelines. These amendments establish new criteria for conducting repairs: rather than prescribing a specific repair method, the rulings rely on engineering data to establish suitable methods for returning the pipe to within acceptable service limits. The requirements in Part 192 leave open the possibility of using composites for higher pressure natural gas transmission, but exceptions would have to go through an approval process.

5.2 State Regulations

Due to limited time and funding a detailed analysis of state regulations was not conducted. An internet search of every states official web site(s) was however conducted, searching for information on the topics of pipeline regulation and safety. In all but 3 cases, some form of pipeline regulation at the state level was identified. Section 5 of the Natural Gas Pipeline Safety Act of 1978 (49 USC 1674) requires that each state participating in the federal/state pipeline safety program certify that it has adopted the federal safety standards established under the act, that is applicable to interstate pipeline transportation under the states jurisdiction. Almost all of the states invoke the federal safety standards found in CFR 49, for intrastate pipeline transmission as well. Typically the state laws have a simple statement such as "Part 192 Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards is incorporated by reference". Some states augment or amplify the federal regulations by adding additional requirements. In a number of cases the additional requirements addressed flowlines and distribution lines.

Appendix C lists the individual states and provides summary information on whether the individual state regulations refer to the CFR's, Flowlines, Gathering Lines, Transmission Lines, Distribution Lines, and Composite Pipe.

5.3 Municipal or Local Regulations

Due to the limited scope of this investigation, municipal and local regulations were not researched, other than the two municipalities that the authors reside in. There was no attempt to gather any other information on municipal distribution systems.

5.4 Other Agencies and Associations

There are dozens of other agencies and associations that take an active interest in natural gas pipeline operations and issues. They range from the Office of Pipeline Safety, a federal agency under the Department of Transportation, with the mission to "Ensure the safe, reliable, and environmentally sound operation of the nation's pipeline transportation system" [11] to the American Public Gas Association, a nonprofit trade organization that represents publicly owned natural gas local distribution companies. Another important association is the National Fire Protection Association (NFPA) an international nonprofit organization with a mission to reduce fires by "providing and advocating scientifically based consensus codes and standards, research, training and education." [12] Many of these organizations fund research and development programs that benefit the natural gas pipeline industry.

6. STANDARDS, SPECIFICATIONS AND RECOMMENDED PRACTICES

A major part of this investigation was spent reviewing the various industry standards, specifications and recommended practices. 49 CFR 192 "Transportation of Natural or Other Gas by Pipeline: Minimum Federal Safety Standards" cites 24 standards alone. These citations include standards from the American Society for Testing and Materials (ASTM), American Petroleum Institute (API), American Society of Mechanical Engineers (ASME) and other institutions. These standards, specifications and recommended practices are the backbone of the state and federal regulations for transportation of natural gas. In order to obtain approval for new natural gas pipeline technologies from the U.S. Department of Transportation's Research and Special Programs Administration, it is necessary to meet the requirements in a number of standards and specifications. These standards and specifications are written for specific materials including steel, fiberglass-reinforced composites (FRP) polyethylene and other plastics.

Listed in **Appendix D** are summaries of 21 specifications, standards, test methods and recommended practices that are directly applicable to pipe used to transport natural gas**.** This Appendix lists the major standards, specifications and recommended practices that apply to the natural gas transportation industry in a table format. Each of the documents listed contain a number of requirements that must be met before pipe can be used to transport natural gas. The requirements include items such as burst pressure, tensile properties, time-to-failure, hoop strength, external loading, hydrostatic pressure design basis, and many others. It is beyond the scope of this investigation to list all of the individual requirements that could apply to design, manufacture, testing, installation, and operation of composite pipe used for natural gas transmission.

7. CURRENT USE OF COMPOSITE PIPE IN THE NATURAL GAS INDUSTRY

There are literally hundreds of manufacturers of fiberglass composite pipe and polyethylene pipe in the United States alone. Pipe production in general is difficult to assess, let alone, pipe production for natural gas applications specifically. Composite and plastic materials are being used for natural gas transportation in flowlines, gathering and distribution pipeline systems. As mentioned in the industry summary above, there are limited test of Composite Reinforced Line Pipe (CRLP) taking place in transmission pipeline situations. The industry uses considerable amounts of composites in flowline applications in natural gas fields. In smaller diameters that can be spooled and transported to onshore locations, composites and plastics are an economical substitute for steel pipe. They have proven their versatility in low to medium pressure flowline applications. Composite use in gathering lines is also becoming increasingly popular. As stated previously, gathering lines have a complex definition that can include the entire system from wellhead to customer. The greatest use of composites in gathering lines again occurs in the gas fields, prior to final treatment of the gas before entry into transmission lines. The gas in these situations is generally at low to moderate pressure, being controlled at the wellhead and processing facilities. These lower pressures again make composites a logical and economical choice.

7.1 Operating Conditions for Transmission and Distribution

Maximum operating pressures for transmission pipelines transporting natural gas are determined by federal regulations that take into account the type of material (steel, composite, plastic, etc.) the diameter of the pipe, the wall thickness, the joining method and a number of other factors. The methods for determining the pressure ratings are detailed in the numerous standards, specifications and recommended practices discussed previously. Transmission lines are required to be tested periodically and the maximum pressure they can be operated at can be down rated. Interstate natural gas transmission pipelines can be operated at very high pressures. For example, the Maritimes Northeast Transmission line is rated at 1440 psi for the 24”-30” line. The Maine Natural gas distribution line fed by the Maritimes Northeast transmission line is rated at 463 psi. In some states the 463 psi line would be considered a transmission line by pressure alone. The distribution/transmission classification in some states is tied to the allowable stress yield of the pipeline material. The portion of the distribution systems that takes natural gas from the gas company mains to the individual customers are generally limited to less than 100 psi, however there are some localities where waivers have been granted and higher pressures serving individual customers are allowed.

Distribution lines to customer’s property are typically made of steel, cast iron, medium-density-polyethylene (MDPE) and high-density-polyethylene (HDPE). New lines installed today are almost all polyethylene based. This is due to polyethylene’s physical properties related to strength, weight and toughness as well as being cost effective and easy to work with. Typically the line pressure at the meter at homes or business is about 60 psi.

8. MATERIAL PROPERTIES (ADVANTAGES AND LIMITATIONS)

When comparing the physical characteristics of steel, fiberglass and plastic based pipe materials, steel has the advantage when pressure is the critical factor. Steel pipe pressure ratings can exceed 5,000 psi depending on pipe size and location of installation. HDPE pipe use in natural gas transportation is limited by 49 CFR 192 to less than 100 psi. Waivers to this pressure limitation are allowed but this product is not used for pressures typical of transmission or trunk distribution lines. FRP prepared from aromatic amine cure epoxy resins have been tested at pressures > 3,500 psi in diameters ranging from 2-3", and approximately 2,750 psi in 4-10" diameter pipe. Ailphatic amine cured epoxy pipe has been certified at 3,750 psi for 2" and up to 1,100 psi for 8" diameter pipe, however this investigation did not find any instances where natural gas was being transported in composite pipe at high pressures.

Thermoplastic pipe is susceptible to a reduction in mechanical properties at elevated temperatures. 49CFR192.123 limits HDPE pipe to 100 psi at up to 100ºF. FRP mechanical properties are also reduced with increased heat, but not generally as dramatically as HDPE. Fiberglass based pipe pressure certifications are generally valid up to around 200ºF. There are some vinyl ester pipe materials that retain properties up to about 300ºF but in general temperature is much more of an issue than with steel pipe.

There are other advanced composites that are currently being used in natural gas field production applications. These spoolable composites are manufactured in sizes ranging from 1 – 4-1/2 inches and continuous lengths up to 35,000'. This type of pipe has a thermoplastic liner surrounded by a hybrid laminate made of carbon, glass or other fibers in an epoxy resin base. All of the strength in this pipe comes from the outer laminate layer. This allows for use of different materials for the thermoplastic liner. This spoolable pipe has pressure ratings ranging from 750 – 5000psi. A drawback with this system is that due to the spooling process, microcracks will develop in the laminate layer. Testing has shown that some outer laminate layers will begin to "weep" due to micro-permeation at pressures exceeding 600 psi when no liner is used. The type of thermoplastic liner material chosen determines the suitability for each application.[13,14]

Generally speaking, the weakest point in a composite pipeline is at the joint. There are a number of joining systems available for composite pipe. Joining methods include Butt-and-Wrap, O-Ring, Flush Thread, Flanged, Keway Joint, Socket Joint (coupled), Threaded and Bonded, Bell and Spigot (matched tapered). With FRP, the strongest joint is a butt-and-wrap joint. Unfortunately this type of joint is both labor and time intensive, requiring multiple applications of resin and reinforcing material with curing time between each application. Coupled joints required gluing or cementing the joints of pipe together using couplings made of the same material. This system works well with low-pressure distribution systems, but is generally not used in higher pressure pipeline applications. A variation of this is the couple-and-wrap method that is similar to a butt-and-wrap with a coupling. Threaded FRP pipe with a box and pin configuration is also widely used in oilfield applications. Maintaining a complete seal in natural gas pipelines at higher pressures however is a challenge with this method of connection. Pipe with flanged connections is quick to install, but larger diameters are difficult to work with, and flanged pipe is not cost competitive. A single 24" flange can cost in the range of $750 to $1000 compared to $100 to $250 per foot for the pipe depending on fabrication method and quality. With spoolable composite pipe, the joints are minimized and installations over long distances are maximized. Unlike FRP, the joints don't rely on secondary bond characteristics. Spooled pipe can be laid at rates considerably higher than conventional steel or fiberglass "stick" pipe.

8.1 Quality Control and Reliability

There is no long-term service history to defend the use of composites in natural gas transmission. However, composite pipe has been manufactured and installed for over 40 years, mainly in applications where chemistry and corrosion is a problem. There is a long-term service history to defend composites in these applications and industries, most notably in related natural gas gather and down hole piping systems. Quality control during pipe manufacture becomes an issue for FRP. There is more room for human error, given the current manufacturing method. Manufacturing of FRP does not require a large investment in tooling, and therefore there are hundreds of smaller manufacturers, and a hand-full of larger manufactures making FRP in a regular basis in the U.S. alone. Quality control varies dramatically throughout the industry.

8.2 Steel vs. Composites

In comparing composites to steel, there are a number of areas where composites are superior. It must be noted that currently, cost of composite pipe is higher on all fronts. Composites are sold, however, on life cycle cost assessment and maintenance advantages. If steel is serving the need adequately, composites are usually extremely difficult to sell. Steel pipe is widely used in production, gathering, transmission and distribution of natural gas.

Comparing relative flexural strengths, composites are significantly more flexible than steel. This has several benefits, but is most relevant when combined with expansion coefficients in that fewer expansion joints are required in a composite pipe system. Composite are highly resistant to many corrosive chemicals and compounds, including H_2S. Some pipelines, including the TransCanadian pipeline have wrapped steel pipe with composites to improve the structural properties, while at the same time adding external corrosion resistance that the steel previously lacked. Composites are significantly lighter than steel. In fact, when strength-to-weight ratios are examined, composites can be much “stronger” than steel. Some composites can be manufactured in continuous “spoolable” lots that facilitate transportation and field installation.

Depending on class, steel pipe ratings are generally reduced by a design factor of 0.40 to 0.73. Additional restrictions are used to further reduce the design factor when location or conditions warrant. Composite pipe is also derated in many applications, to introduce an added safety factor.

Steel has better abrasion resistance. However, additives can be included in composite pipe fabrication to increase abrasion resistance. Installation of buried composite pipe is comparable to steel, though more care needs to be taken regarding the “trench” contents to avoid rock punctures, etc. That said, work is currently being done with resin systems that are significantly more impact resistant. Compressive edge strength of a vinyl ester based glass composite is 24,000 psi – roughly 67% that of A36 steel.

8.3 Environmental Considerations

Increased production and use of composites in pipelines brings up unique environmental issues that don't occur with steel production. Environmental regulatory agencies are most concerned with the use of styrene in composite manufacturing. Many different chemicals are used as monomers in composite production, but styrene is used most extensively. Styrene is a clear liquid with a distinctive odor. Styrene is widely used because; it can be combined with a variety of polymers to form resins, it's physical properties when used with other polymers are well known and predictable, and it imparts important physical properties to the final product, and it is readily available and relatively inexpensive. The U.S. EPA and other U.S. and foreign government institutions have extensively studied styrene and its effects on humans and the environment. Some of these agencies have already reported that styrene "does not constitute a danger to human life and health" and "does not constitute a danger to the environment on which human life depends."[15] The director of the U.S. EPA signed the proposed NESHAP Maximum Achievable Control Technology (MACT) standard for the Reinforced Plastics/Composites source category on June 22, 2001. Environmental concerns will become a greater issue for composite manufacturers in the future.

9. RESEARCH

There are approximately a dozen major universities around the world and dozens more smaller universities and colleges with composites research groups. In addition, there are some nonprofit and private groups such as the Gas Research Institute that perform composite research. Finally, most of the major composite end product manufacturers and component part manufacturers (resin, fibers, plastics, etc.) perform research and development functions.

A comprehensive research program for application of composite materials to natural gas pipeline service, primarily focused on gas transmission line service, should both evaluate recent and current research activities for application to gas transmission conditions and transmission line specific issues.

A summary of recent and ongoing composite research and a list of additional research needed for natural gas transmission pipeline service is provided in sections 9.1 and 9.2 respectively. Appendix E. Research Capabilities and Publications provides additional research related information including composite related websites, selected journals with composite research or topics and a partial list of universities with composite research programs. It is important to note that much of the composite research done is not directed specifically toward the pipe industry, but almost all composite research has cross-over applications.

9.1 Current and Recent Research Topics

- Development of large diameter reinforced thermoplastic pipe with high pressure and high temperature resistance for subsea petroleum production installation
- Stress near the surface of thick composite pipe
- Repair of metals with composites and composite patch reinforcements
- Fatigue modeling in fiberglass reinforced composite materials
- Erosive and abrasive wear of individual composite constituents
- Composite Manufacturing NDE Using Active Infrared Thermography
- Predicting failure of composite structures
- Damage, fracture and failure of composites. Basic physical mechanisms of delamination, matrix cracking and strain softening
- Craze/void nucleation in composites
- Stress relaxation in bolted joints as related to fiber type, volume and matrix

- Impact and ballistics of composites. Analytical and numerical models for predicting impact response of laminated composites.
- Mechanical behavior and ageing of polymer-matrix composites
- Analysis of standardized test methods used to develop material properties
- Joining composites including glass-fiber composites to metal
- Microstructure architecture of composites
- Microstructures and improvements in mechanical performance of composites
- Fiber-matrix interfacial strength
- Design of fraction gradient and reinforcement coatings to reduce surface damage
- Carbon-carbon composites properties determination and new applications
- Processing science – fiber placement, curing, bonding, filament winding and novel processing techniques
- Processing cycles of thermosetting polymer-matrix composites. High costs associated with long processing cycles in manufacture (cure cycles). Numerical modeling of the time-optimal fabrication cycle
- Materials synthesis on a macro and micro scale
- Machinery for low-cost composite fabrication

9.2 Barriers and areas of needed research

Composite pipe use has been established in flowline, gathering line, and distribution systems associated with natural gas transmission. Flowline and gathering line systems share common barriers, but they are for the most part being adequately addressed by industry. By far the biggest technology challenge is finding stronger, less expensive and longer lasting pipeline materials for large diameter, high pressure / high volume interstate and intrastate natural gas transmission systems. Metal/plastic hybrids are just beginning to be tested under very restricted conditions in these applications (TansCanada Pipelines system test discussed in the Natural Gas Industry section above). Nonmetallic RTRP composite pipe for high-pressure interstate gas transmission has not been developed and therefore shows the greatest potential for further research.

9.3 Transmission System Barriers and Future Research

For purposes of this discussion transmission lines can be classified as > 8 inch and > 500 psig. Many operate in the 1000-2000psi range. The barriers to using composite in transmission lines are both financial, technology and perception based. Current resin/fiber based composite pipe is far more expensive than steel in the sizes need for transmission lines. However, fiber-reinforced polymerics (FRP) are being looked at because of their superior corrosion resistance and high strength-to-weight ratio. Composite-Reinforced-Line-Pipe, a steel composite hybrid is currently being tested on the TansCanada system. Some of the barriers that limit consideration of composites for natural gas transmission pipelines are:

- Understanding of large diameter composite material pipe under varying loading and environmental conditions
- External damage from handling and transportation of composite pipe
- External damage from puncture and abrasion during or after field installation and handling
- Joining and valving of composite pipe used for high pressure operations needs to be more reliable and less expensive
- Material behavior under variable load conditions
- Quality control and inspection during manufacturing processes. NDE and other
- Quality control and inspection during installation processes. NDE and other
- Inspection of in-service lines
- Regulatory acceptance of pure composite (non-steel) pipe for high pressure natural gas applications. Federal acceptance and licensing. State acceptance and licensing.
- Training for state and federal agencies and oversight groups who would regulate and administer composite pipe natural gas transmission systems
- Public perception and acceptance of pure composite pipeline for high pressure gas transmission
- Susceptibility to damage from digging and excavation

All of the areas listed above are potential research areas, but some such as transportation and handling would be further in the future. Research areas that could provide quick dividends include:

- Composite materials – resins and fibers. Combinations of exotic fibers and traditional materials to maximize strength and minimize cost. Compatibility of these materials with natural gas products
- Joining of Composite materials, composite to composite and composite to metal
- On site manufacture of continuous lengths of composite pipe – equipment design, materials
- On site coating or overlay of steel pipe with a composite material prior to burial
- Armoring or coating of RTRP pipe with new resins, new fibers or combinations of the two

- Material failure through delamination and joint failure
- Automated quality control systems

9.4 Flowline Systems Barriers and Future Research

Flowline systems typically fall in the 2-4 inch diameter range. Gathering pipeline systems typically fall in the 2-6 inch diameter range. The industry is currently using composite pipe such as Fiberspar® Linepipe™ in flowline and gathering line applications. These types of products are resistant to corrosion and can handle high flow pressures. It appears that these types of spoolable fiber reinforce polyethylene pipe are already well on the way to making composites the first choice in oilfield flow lines. Although many of these products are rated for high pressures, the installation designs call for derating factors that can considerably lower the maximum operating pressure. Public perception is not a factor in oilfield applications of composite pipe. Some of the barriers that limit consideration of composites for natural gas flowline and gathering line applications are:

- Susceptibility to damage during installation and operation. In some areas flowlines are laid on the surface and not buried
- Pressure limitations
- Joining Technology

Flowline and gathering line pipe is a highly competitive market in which industry maintains well developed cutting edge research capabilities. Therefore no research topics are presented or recommended.

9.5 Distribution Systems Barriers and Future Research

Plastics (polyethylene) are widely used in low-pressure gas distribution systems. They are inexpensive, can be spooled, are easy to join and trusted by the industry and public. Toughness may be a minor drawback of plastics, which composites could outperform. It appears it would by hard to displace plastics in distribution systems applications. Plastics such as HDPE already have the major portion of the distribution pipeline market. These lines have a much higher potential to being disturbed after installation, due to frequent excavating done in metropolitan and residential areas. A pipe better able to withstand construction accidents would be a welcome addition. Research involving external damage control on the large diameter natural gas transmission lines would likely have some spin-off applications on distribution lines.

10. SUMMARY AND RECOMMENDATIONS

The following summarizes what we found in this preliminary investigation of composite pipe use for natural gas transmission.

1. The term "composite" when applied to pipe has a very open and broad definition that covers pipe manufactured from fiberglass and resins, plastic, carbon and other synthetic materials, and combinations of all of these with conventional steel pipe.

2. Composite pipe is being used in the natural gas transmission industry, primarily in flowlines and gathering lines in the upstream segment of the oil and gas industry. Plastic pipe is widely used in the distribution systems. These three natural gas pipeline applications, flowline, gathering line and distribution line do not offer areas where new research will make order of magnitude advances in cost and safety. The area where research can offer significant potential is for large diameter high pressure transmission lines.

3. Composite materials research is moving forward on many fronts. Research is being conducted in the areas of materials chemistry, bonding, stress and fatigue, joining, manufacturing (processes and equipment) and a host of other topics by dozens of university research centers around the world. In addition, many of the manufacturers of composite materials and pipe are conducting proprietary research in their in-house research and development centers.

4. In order for composite pipe, and RTRP in particular, to be the pipe of choice in the high pressure/high volume natural gas transmission industry, the following barriers and issues would have to be addressed:

   - Expense of raw materials
   - Manufacturing costs including unit-time to manufacture
   - Quality control in manufacture of composite pipe for high pressure applications
   - Transportation costs (currently lighter weight but higher volume)
   - Strength and durability. Less material per linear foot with increased resistance to external damage (especially puncture and abrasion)
   - Field installation and joining technology (ability to make quick joints that can withstand high pressure)
   - Regulatory restrictions on pressures allowed in composite and plastic pipe
   - NDE of operating composite pipelines

Recommended topics and areas of research for large diameter, high pressure, high volume transmission pipelines include:

- Composite materials – resins and fibers. Combinations of exotic fibers and traditional materials to maximize strength and minimize cost in natural gas pipe applications
- Joining of Composite materials, composite to composite and composite to metal
- On site manufacture of continuous lengths of composite pipe – equipment design, materials
- On site coating or overlay of steel pipe with a composite material prior to burial
- Armoring or coating of RTRP pipe with new resins, new fibers or combinations of the two
- Material failure through delamination and joint failure
- Automated quality control systems

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6. NETL Call for Proposal – *Reference for Definitions of Transmission and Distribution lines*

7. Lacovara, Bob "*What Exactly are Composites? Do We Take The Definition for Granted?"*, Composite Fabricators Association Website http://www.cfa-hq.org/techsvcs.shtml#library

8. Beckwith, Scott W, "*Filament Winding – The String and the Glue*", Beckwith Technology Group http://www.cfa-hq.org/techsvcs.shtml#library

9. ASTM D 2924-01 *Standard Test Method for External Pressure Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe*, August 2001

10. ASTM D 2996-01 *Standard Specification for Filament-Wound "Fiberglass"*

11. U.S. Department of Transportation, Office of Pipeline Safety Research and Special Programs Administration website htpp://www.ops.dot.gov

12. National Fire Protection Association website htpp://www.nfpa.org

13. http://www.hydril.com/spoolable/introspool2.htm Hydril Company LP

14. http://www.fiberspar.com/ Fiberspar Co.

15. http://www.cfa-hq.org/emissions_q&a.htm Composite Fabricators Association website "Q&A Composites Manufacturing Emissions"

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17. DeWolf, Glenn; Joseph, Giby; Leewis, Keith,1999, *Advanced Pipe Initiative for Inherently Safer Pipe: A Preliminary Assessment,* GRI-99/0098, May 1999. (Report Summary on GRI web page) by Radian International LLC, Austin, TX; Gas Research Institute, Chicago, IL, for Gas Research Institute, Chicago, IL

Appendix A

Definitions

Appendix A. Definitions

According to the CFR 49 Part 192, a **distribution line / distribution system** is defined as a pipeline other than a gathering or transmission line. A Distribution System according to the CFR 49 part 191 is "the gas distribution pipeline system supplies the ultimate consumer who either purchases the gas directly through a meter or by other means such as by rents." The CFR's go on to define a High Pressure Distribution System as "a distribution system in which the gas pressure in the main is higher than the pressure provided to the customer. The final step in the distribution system is the service line that connects the customers line to the gas provider's line. The CFR's define a service line as a distribution line that transports gas from a common source of supply to (a) a customer meter or the connection to a customer's piping, whichever is farther downstream, or (b) the connection to a customer's piping if there is no customer meter. A customer meter is the meter that measures the transfer of gas from an operator to a consumer. (49CFR Part 192, Subpart A–General §192.3 Definitions.) For the purpose of this investigation, we will define a distribution system as "The gas distribution piping system that delivers gas from the transmission system (or city gate) to the customer meter. Distribution piping systems consist of mains and services. A "main" is a pipe installed in a community to convey gas to individual service lines. A "service line" is the piping installed between a main or other source of supply, and the customer meter set assembly." [6]

In addition for the very specific definitions for the various transmission systems, the regulations have specific definitions for the pipe that carries the gas. The following are definitions taken from 49 CFR Part 192, that apply to pipe.

Pipe means any pipe or tubing used in the transportation of gas, including pipe-type holders.

Pipeline means all parts of those physical facilities through which gas moves in transportation, including pipe, valves, and other appurtenance attached to pipe, compressor units, metering stations, regulator stations, delivery stations, holders, and fabricated assemblies.

Pipeline facility means new and existing pipeline, rights-of-way, and any equipment, facility, or building used in the transportation of gas or in the treatment of gas during the course of transportation.

Composites is a term that has varying meanings among engineers and manufacturers. In the most general of definitions, a composite consists of "Two or more dissimilar materials which when combined are stronger than the individual materials."[7] This general definition covers the various type of pipe currently being used in the transmission of natural gas which includes metal, plastic, and thermosetting resin pipe as well as various combinations of the three. A more precise definition for thermosetting composites would be "a combination of a reinforcement fiber in a thermoset polymer resin matrix, where the reinforcement has an aspect ratio that enables the transfer of loads between fibers, and the fibers are chemically bonded to the resin matrix."[7] Characteristics of composites that make them ideal candidates for natural gas transmission include resistance to chemical and cathodic corrosion, high strength, lightweight, and flexibility. Generally speaking, composites have a higher strength-to-weight ratio that steel. With the ability o control the type, amount and direction of application of the reinforcement material, composite pipe becomes an ideal candidate for widely varying pressure applications.

Fiberglass pipe is defined in the ASTM standards as a "tubular product containing glass fiber reinforcements embedded in or surrounded by cured thermosetting resin. The composite structure may contain aggregate, granular or platelet fillers, thixotropic agents, pigments, or dyes. Thermoplastic or thermosetting liners or coatings may be included."[9] (ASTM D 2924-01). The two most common types of fiberglass pipe are reinforced-thermosetting-resin-pipe (RTRP) which is defined by the American Society for Testing and Materials (ASTM) as fiberglass pipe without aggregate and glass-fiber-reinforced polymer mortar pipe (RPMP) which is a type of fiberglass pipe with aggregate added to the matrix. In the oil industry, fiberglass pipe, is also commonly referred to as Fiberglass Reinforced Plastic (FRP), or Glass Reinforced Epoxy (GRE).

Composite Reinforced Line Pipe (CRLP) consists of steel pipe coated or wrapped in a continuous composite shell material that adds strength and protection to the steel. CRLP is relatively new and has not been specifically defined in the ASTM standards.

Polyethylene is a linear polymer prepared from ethylene. Polyethylene can be formed in high, medium or low density versions and is particularly easy to mold when forming. High Density Polyethylene (HDPE) is characterized by a more closely packed structure that results in a higher density, higher chemical resistance, and a somewhat higher operational temperature than medium (MDPE) and low (LDPE) density polyethylene. This material is easy to form into pipe that is light, tough, chemical resistant and can be spooled. HDPE is used in the transportation of natural gas in both distribution lines, and flowlines, as well as some new applications as a composite with steel and fiber products.

Appendix B

Federal Regulations

Appendix B Federal Regulations

Code of Federal Regulations

In the federal regulations there is a clear distinction between interstate and intrastate natural gas transmission. An intrastate gas pipeline facility (pipeline, right-of-way, facilities, buildings and equipment used to transport natural gas) is not subject to the jurisdiction of the Federal Energy Regulatory Commission under the Natural Gas Act (15 U.S.C 717 et seq.), if it meets certain minimum safety standards and is regulated by the state.

> Sec. 60105 - State pipeline safety program certifications
> (a) General Requirements and Submission. - Except as provided in this section and sections 60114 and 60121 of this title, the Secretary of Transportation may not prescribe or enforce safety standards and practices for an intrastate pipeline facility or intrastate pipeline transportation to the extent that the safety standards and practices are regulated by a State authority (including a municipality if the standards and practices apply to intrastate gas pipeline transportation) that submits to the Secretary annually a certification for the facilities and transportation that complies with subsections (b) and (c) of this section.

Interstate pipeline facilities are subject to jurisdiction of the Commission. In the federal regulations, transportation of gas is defined as:

> "transporting gas" - (A) means the gathering, transmission, or distribution of gas by pipeline, or the storage of gas, in interstate or foreign commerce; but (B) does not include the gathering of gas, other than gathering through regulated gathering lines, in those rural locations that are located outside the limits of any incorporated or unincorporated city, town, or village, or any other designated residential or commercial area (including a subdivision, business, shopping center, or community development) or any similar populated area that the Secretary of Transportation determines to be a nonrural area, except that the term "transporting gas" includes the movement of gas through regulated gathering lines;

Under section 49 of the Code of Federal Regulations, there are 8 parts (190-195 and 198-199) that specifically address the transmission of natural gas. A brief description of each of these parts is provided below.

CFR 49 Part 190 sets forth procedures used by the Research and Special Programs Administration to perform duties associated with pipeline safety under the pipeline safety laws (49 U.S.C 60101 et seq.)

CFR 49 Part 191 sets forth requirements for reporting incidents, safety-related conditions, and annual summary data reported by operators of pipelines. It does not apply to onshore gathering of gas outside of cities, towns or villages, subdivisions or business centers. There are also specific limitations on offshore applicability.

CFR 49 Part 192 Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards) is the foundation of the natural gas transmission rules and regulations in the US. This part sets forth minimum safety requirements for pipelines. CFR 49 Part 192.619 is the section that limits natural gas distribution pipeline systems to a maximum allowable operating pressure of 100 psig. This design-limitations section also sets minimum wall thickness for thermoplastic pipe and reinforced thermosetting plastic pipe used in natural gas transmission.

CFR 49 Part 193 prescribes safety standards for liquid natural gas (LNG) facilities and transportation. The regulations here do not apply to LNG facilities used by the ultimate consumer of LNG or those facilities used on the course of extraction or treatment that do not store LNG.

CFR 49 Part 194 contains information and requirements associated with oil spill response.

CFR 49 Part 195 contains the prescribed safety standards and reporting requirements associated with pipeline facilities that transport carbon dioxide or hazardous liquids. Natural gas is not considered a hazardous liquid under this section. It's of interest in this report to note that this regulation requires the use of steel or carbon pipe for transmission of hazardous liquids or carbon dioxide.

CFR 49 Part 198 sets forth requirements and regulations that govern grants-in-aid for State pipeline safety compliance programs.

CFR 49 Part 199 provides the guidance and requirements for operators of pipeline facilities to test employees for the presence of prohibited drugs and provide for employee assistance programs.

Appendix C

State Regulations

Appendix C State Regulations

State	References 49 CFR 192 as Minimum Standards	Regulates Flowlines	Regulates Gathering Lines	Regulates Transmission Lines	Regulates Distribution Lines	Refers to Composite Pipe
Alabama	NF	Yes	Yes	Yes	NF	NF
Alaska	NF	NF	NF	NF	NF	NF
Arizona	NF	NF	NF	NF	NF	NF
Arkansas	Yes	NF	Yes	NF	Yes	NF
California	NF	NF	NF	NF	NF	NF
Colorado	Yes	Yes	NF	NF	NF	NF
Connecticut	NF	NF	NF	NF	NF	NF
Delaware	NF	NF	NF	NF	NF	NF
Florida	Yes	NF	NF	Yes	Yes	NF
Georgia	Yes	NF	NF	NF	NF	NF
Hawaii	NF	NF	NF	NF	NF	NF
Idaho	Yes	NF	NF	NF	NF	NF
Illinois	Yes	NF	NF	NF	NF	NF
Indiana	Yes	NF	Yes	Yes	Yes	NF
Iowa	Yes (U.S.C.)	NF	NF	Yes	NF	NF
Kansas	Yes	NF	NF	NF	NF	NF
Kentucky	Yes	NF	NF	NF	NF	NF
Louisiana	Yes	NF	Yes	Yes	Yes	NF
Maine[1]	NF	NF	NF	NF	NF	NF
Maryland	Yes	NF	NF	NF	Yes	NF
Massachusetts	Yes	NF	NF	NF	Yes	NF

State	References 49 CFR 192 as Minimum Standards	Regulates Flowlines	Regulates Gathering Lines	Regulates Transmission Lines	Regulates Distribution Lines	Refers to Composite Pipe
Michigan	Yes	NF	NF	NF	NF	NF
Minnesota	Yes	NF	Yes	Yes	Yes	NF
Mississippi[2]	NF	NF	NF	NF	NF	NF
Missouri	Yes	NF	NF	NF	NF	NF
Montana[3]	NF	NF	NF	NF	NF	NF
N. Carolina	NF	NF	NF	NF	NF	NF
N. Dakota	Yes	NF	NF	Yes	Yes	NF
Nebraska	Yes	NF	NF	NF	NF	NF
Nevada	Yes	NF	NF	NF	NF	NF
New Hampshire	NF	NF	NF	NF	NF	NF
New Jersey[4]	NF	NF	NF	NF	NF	NF
New Mexico	Yes	NF	Yes	Yes	Yes	NF
New York[5]	NF	NF	NF	NF	NF	NF
Ohio	Yes	Yes	NF	NF	NF	NF
Oklahoma	Yes	NF	Yes	Yes	Yes	NF
Oregon	Yes	NF	NF	NF	NF	NF
Pennsylvania	Yes	NF	NF	NF	NF	NF
Rhode Island	Yes	NF	NF	NF	NF	NF
S. Carolina	Yes	NF	NF	Yes	Yes	NF
S. Dakota[6]	NF	NF	NF	NF	NF	NF
Tennessee	Yes	NF	NF	NF	NF	NF
Texas	Yes	Yes	Yes	Yes	Yes	Yes

State	References 49 CFR 192 as Minimum Standards	Regulates Flowlines	Regulates Gathering Lines	Regulates Transmission Lines	Regulates Distribution Lines	Refers to Composite Pipe
Utah	**Yes**	**NF**	**NF**	**Yes**	**NF**	**NF**
Vermont	**Yes**	**NF**	**NF**	**Yes**	**Yes**	**NF**
Virginia	**Yes**	**NF**	**NF**	**NF**	**Yes**	**NF**
W. Virginia	**NF**	**NF**	**NF**	**Yes**	**Yes**	**NF**
Washington	**Yes**	**NF**	**NF**	**NF**	**NF**	**NF**
Wisconsin	**Yes**	**NF**	**NF**	**NF**	**NF**	**NF**
Wyoming	**Yes**	**NF**	**Yes**	**NF**	**NF**	**NF**

NF – Not Found

[1]Maine – Has laws, but it's not clear on the internet search, exactly what is covered.

[2]Mississippi – Has references on the state web page but it was not clear what was covered by state laws.

[3]Montana – Has rules and regulations for pipeline carriers

[4]New Jersey – Not available on the web. Requires that you purchase the information.

[5]New York - Has references on the state web page but it was not clear what was covered by state laws.

[6]South Dakota – A South Dakota PUC document has a statement that says the state has enacted rules and regulations "to replace the federal pipeline safety program which proved incapable of meeting safety mandates within South Dakota"

Appendix D

CFR's, Standards, Specifications and Recommended Practices

Appendix D CFR's, Standards, Specifications and Recommended Practices

A major part of this investigation was spent reviewing the various industry standards, specifications and recommended practices. 49 CFR 192 "Transportation of Natural or Other Gas by Pipeline: Minimum Federal Safety Standards" cites 24 standards alone. These citations include standards from the American Society for Testing and Materials (ASTM), American Petroleum Institute (API), American Society of Mechanical Engineers (ASME) and other institutions. These standards, specifications and recommended practices are the backbone of the state and federal regulations for transportation of natural gas. In order to obtain approval for new natural gas pipeline technologies from the U.S. Department of Transportation's Research and Special Programs Administration, it is necessary to meet the requirements in a number of standards and specifications. These standards and specifications are written for specific materials including steel, fiberglass-reinforced composites (FRP) polyethylene and other plastics.

Listed below are summaries of 21 specifications, standards, test methods and recommend practices that are directly applicable to pipe used to transport natural gas. **Appendix D** lists the major standards, specifications and recommended practices that apply to the natural gas transportation industry in a table format. Each of the documents listed contain a number of requirements that must be met before pipe can be used to transport natural gas. The requirements include items such as burst pressure, tensile properties, time-to-failure, hoop strength, external loading, hydrostatic pressure design basis, and many others. It is beyond the scope of this investigation to list all of the individual requirements that could apply to design, manufacture, testing, installation, and operation of composite pipe used for natural gas transmission. The following apply to Thermoplastic / Polyethylene / RTRP composites. Some of these apply to plastic pipe. It is assumed that new composite pipe developed for future natural gas transmission may have some plastic component also.

American Petroleum Institute

Established in 1919 when the government and the oil and gas industry agreed to work together for a reliable supply of petroleum products for the military to fight World War I, the American Petroleum Institute (API) has grown to be the U.S. oil and gas industries primary trade organization. API provides regulatory advice based on scientific research and works with other oil and gas industry associations to develop standards and policies for the energy industry. The API standards are written and published to provide standard engineering and operating practices for the oil and gas industry. The standards and recommended practices are also intended to be used by companies as aids for the procurement of standardized equipment, materials and engineering services. The API standards and recommended practices are not intended to limit engineers and pipeline companies from designing, testing and installing new or novel materials and processes. In fact the standards are reviewed and revised on a periodic basis to keep up with changes in technology. A brief description of the key API standards and recommend practices that affect the natural gas transportation industry follows.

API 15HR Specification for High Pressure Fiberglass Line Pipe (3rd Ed. 8/01) details specifications for fiberglass pipe that can be used in pressure rated systems from 500 psi to 3,000 psi. Pipe included in this specification is limited to that with mechanical connections.

API 15LR Specification for Low Pressure Fiberglass Line Pipe (6th Ed. 9/1/90) covers the manufacturing of fiberglass line pipe manufactured by the centrifugally cast (CC) and the filament wound

(FW) processes, using thermosetting polymers reinforced with glass fibers. It includes discussions on quality control testing, hydrostatic mill tests, materials properties, dimensions and weights, and minimum performance requirements. Pipe manufactured under this specification can be up to 16 inches in diameter with cyclic operating pressures of up to 1000 psig. This specification references two API specifications and 12 ASTM standards, procedures and test methods.

API RP 5L2 Recommended Practice for Internal Coating of Line Pipe for Non-Corrosive Gas Transmission Service (3rd Ed. 5/31/87) ANSI/API RP 5L2-87 (Approved 7/12/93) covers application of internal coatings in steel line pipe used in natural gas transportation.

The term tubulars in the petroleum industry generally implies pipe or casing used in a well. API 15TL4 Recommended Practice for Care and use of Fiberglass Tubulars (2nd Ed. 3/99) not only discusses fiberglass oilfield tubulars, but it also has sections on line pipe. This recommended practice discusses installing fiberglass pipe in ditches and on the surface. It also discusses damage that can occur if the bonding surfaces are subjected to prolonged exposure to ultraviolet light.

API 15LE Specification for Polyethylene Line Pipe (3rd Ed 4/1/95) provides standards for the manufacture and testing of polyethylene line pipe and fittings. This type of pipe is commonly used in natural gas distribution systems, running from a trunk line to the customer's meter. This specification references one ANSI specification, 20 ASTM documents, and CFR 49, Part 192.

American Society of Mechanical Engineers

The American Society of Mechanical Engineers (ASME) is an international nonprofit educational and technical organization founded in 1880 with a worldwide membership of over 125,000. ASME committees set many of the industrial and manufacturing standards used in all aspects of engineering and manufacturing. Many of those standards are used in the petroleum industry. A brief description of the key ASME standards that affect the natural gas transportation industry follows.

ASME B31.8-1999 Gas transmission And Distribution Piping Systems (Revision of ASME B31.8-1995) 802.11 applies to the design, fabrication, installation, inspection, and testing of pipeline facilities used for transportation of natural gas. It does not apply to flowlines or LNG piping systems. This code addresses plastic pipe and divides it into two general types;
Thermoplastic, which is a plastic that is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature.
Thermosetting plastic, which is plastic, that is capable of being changed into a substantially infusible or insoluble product when cured under application of heat or chemical means.

American Society for Testing and Materials (ASTM)

The American Society for Testing and Materials (ASTM) was organized in 1898. It has grown into a nonprofit international organization with over 20,000 members that develop voluntary standards for materials, products, systems and services. Many ASTM standards and test methods are cited in the natural gas transportation industry and CFR's. A brief description of some of the key ASTM standards and tests that apply to this investigation are provided below.

ASTM D 1598-97 Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure (D 1598-97) discusses time-to-failure testing in thermoplastic and reinforced thermosetting resin pipe. It provides a standardized method to characterize failure of pipe made of these components.

ASTM D 1599-99 Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings (12/10/99) describes the methods used to determine the burst pressure of thermoplastic and reinforced thermosetting resin pipe and fittings. These procedures can be used to formulate a quality control testing program.

ASTM D 2105-01 Standard Test Method for Longitudinal Tensile Properties of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube (August 2001) is specific to fiberglass pipe, generally less than 6 inches in diameter. It prescribes procedures to determine tensile properties of fiberglass pipe tested at various pretreatment, temperatures and testing machine speeds.

ASTM D 2143-00 Standard Test Method for Cyclic Pressure Strength of Reinforced, Thermosetting Plastic Pipe (February 2001) is specific to reinforced thermosetting plastic pipe and is used to determine failure characteristics of the pipe when subjected to cyclic internal hydraulic pressures. The test is limited to samples with a 10:1 ratio of outside diameter to wall thickness.

ASTM D 2513-01a Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings (8/01) covers polyethylene pipe and fittings that are intended for use in natural gas distribution systems. It does not cover threaded pipe or materials designed for high-pressure use. The tests include those for chemical resistance, hydrostatic burst strength, impact resistance and dimensions and tolerances.

ASTM D 2517-00 Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings (7/00) details requirements and methods of testing reinforced epoxy resin pipe and fittings used in natural gas distribution lines. The reinforced pipe addressed in this specification is made with the filament winding process. The tests include those for chemical resistance, hydrostatic burst strength, longitudinal tensile properties and dimensions and tolerances.

ASTM C 581-00 Standard Practice for Determining Chemical Resistance to Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service (September 2000) evaluates the chemical resistance of thermosetting resins used to make reinforced thermosetting plastic (RTP) laminates. While it is designed for materials intended for liquid service, it could have some application to pipe intended for natural gas service. The tests detailed in this standard practice are applicable to all reinforced thermosetting resin pipe regardless of the method used to fabricate it.

ASTM D 2290 – 00 Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method (September 2000) details sets of tests that are designed to determine the comparative apparent tensile strength of reinforced thermosetting resin pipe, and thermoplastic pipe.

ASTM D 2412-96a Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading (November 1997) sets forth methods to test thermoplastic resin pipe, reinforced thermosetting resin (RTRP) pipe, and reinforced plastic mortar (RPMP) pipe to determine pipe stiffness, stiffness factor and load at specific deflections.

ASTM D 2924-01 Standard Test Method for External Pressure Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe (August 2001) details test methods used on glass-fiber- reinforced thermosetting-resin pipe (RTRF) and glass-fiber-reinforced polymer mortar pipe (RPMP) that are designed to determine the resistance of fiberglass pipe to external pressure such as buckling, compression and leaking.

ASTM D 5685-01 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe Fittings (August 2001) sets forth the standards for fittings used with fiberglass pipe. This standard covers fittings from 1-16 inches and pressures from 25-1000 psig, with specific limitations addressed.

ASTM D 638-01 Standard Test Method for Tensile Properties of Plastics (September 2001) describes the method used to determine the tensile properties of both reinforced and unreinforced plastics at standard temperatures, humidity and testing machine speeds.

ASTM D 2996-01 Standard Specification for Filament-Wound “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe’ (August 2001) provides the classification system, mechanical properties, performance, dimensions methods of testing and marking of thermosetting resin pressure pipe (RTRP) manufactured by the filament winding process up to 24 inch nominal size.

ASTM D 2997-01 Standard Specification for Centrifugally Cast “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe (August 2001) details the specifications for machine-made glass-fiber- reinforced thermosetting-resin pressure pipe manufactured by the centrifugal casting process. It includes a classification system, as well as the requirements for materials, mechanical properties, dimensions, markings, test methods and performance of centrifugally cast fiberglass pipe.

ASTM D 2992-01 Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings (August 10, 2001) provides two procedures used for obtaining a hydrostatic design basis and a pressure design basis for fiberglass pipe.

Document Number	Agency or Organization and Title of Document	Applicability: Steel Pipe	Applicability: Thermoplastic / Polyethylene / RTRP / Composites	Comments
	Code of Federal Regulations (CFR)			
CFR 49 Part 190	CFR 49 Part 190 – Pipeline Safety Programs and Rulemaking Procedures			
CFR 49 Part 191	CFR 49 Part 191 – Transportation of Natural and Other Gas by Pipeline; Annual Reports, Incident Report			
CFR 49 Part 192	CFR 49 Part 192 – Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards	Yes	Yes	
CFR 49 Part 193	CFR 49 Part 193 – Liquefied Natural Gas Facilities: Federal Safety Standards	Yes		Safety standards for liquid natural gas (LNG) facilities and transportation.
CFR 49 Part 194	CFR 49 Part 194 – Response Plans for Onshore Oil Pipelines			
CFR 49 Part 195	CFR 49 Part 195 – Transportation of Hazardous Liquids by Pipeline	Yes	No	Safety standards and reporting requirements associated facilities that transport carbon dioxide or hazardous liquids. Natural gas is not considered a hazardous liquid under this section
CFR 49 Part 198	CFR 49 Part 198 – Regulations For Grants To Aid State Pipeline Safety Programs	Yes	Yes	Pipeline Safety Programs. Does not deal with specific pipe materials
CFR 49 Part 199	CFR 49 Part 199 – Drug and Alcohol Testing			Testing programs required by the Federal Regulations for gas transportation companies.
CFR 33 Part 156	33 CFR 156.170 requires transfer pipelines be tested annually (Coast Guard website)	Yes		Requirement for testing of pipelines used for transfer of petroleum products from offshore locations.
Amendment to CFR 49 Part 192	49 CFR 192-88 / USDOT Docket No. RSPA-98-4733 – Federal Register Vol.64 No. 239, Tuesday, December 14, 1999			Allows companies to employ composite repair techniques on steel pipelines after thorough engineering review. ii) "Clock Spring" composite wrap established in testing with GRI iii) "Armor Plate Pipe Wrap" composite wrap established in testing with Stress Engineering Services
	American Society for Testing and Materials (ASTM)			
ASTM A106-95	ASTM A106-95 "Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service"	Yes	No	Included as reference in 49 CFR 192
ASTM A333/A333M-94	ASTM A333/A333M-94 "Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service"	Yes	No	Included as reference in 49 CFR 192
ASTM A372/A372M-95	ASTM A372/A372M-95 "Standard Specification for Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels"	Yes	No	Included as reference in 49 CFR 192
ASTM A381-93	ASTM A381-93 "Standard Specification for Metal-Arc-Welded Steel Pipe for Use with High-Pressure Transmission Systems"	Yes	No	Included as reference in 49 CFR 192
ASTM A53-96	ASTM A53-96 "Standard Specification for Pipe, Steel Black and Hot-Dipped, Zinc-Coated, Welded and Seamless"	Yes	No	Included as reference in 49 CFR 192
ASTM A671-94	ASTM A671-94 "Standard Specification for Electric-Fusion-Welded Steel pipe for Atmospheric and Lower Temperatures"	Yes	No	Included as reference in 49 CFR 192
ASTM A691-93	ASTM A691-93 "Standard Specification for Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures"	Yes	No	Included as reference in 49 CFR 192
ASTM C 581-00	Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service – ASTM C 581-00 (Published September 2000)	No	Yes	Evaluates chemical resistance of thermosetting resins used to make reinforced thermosetting plastic (RTP) laminates. Test is designed for materials intended for liquid service, but could have some application to pipe intended for natural gas service. Tests in this standard practice are applicable to all reinforced thermosetting resin pipe regardless of the method used to fabricate it.
ASTM D 1598-97	ASTM D 1598-97 Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure (D 1598-97)	No	Yes	Standard test method for time-to-failure testing in thermoplastic and reinforced thermosetting resin pipe.
ASTM D 1599-88	ASTM D 1599-88 Standard Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings (Reapproved 1995)	No	Yes	Standard test method for burst pressure of thermoplastic and reinforced thermosetting resin pipe and fittings.
ASTM D 2105-97	ASTM D 2105-97 Standard Test Method for Longitudinal Tensile Properties of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube	No	Yes	Test method for fiberglass pipe generally less than 6 inches in diameter. Testing to determine tensile properties of fiberglass pipe.

	ASTM D 2143-94	ASTM D 2143-94 Standard Test Method for Cyclic Pressure Strength of Reinforced, Thermosetting Plastic Pipe	No	Yes	Test method for reinforced thermosetting plastic pipe used to determine failure characteristics of the pipe when subjected to cyclic internal hydraulic pressures.
	ASTM D 2290-00	Standard Test Method for Apparent Hoop Tensile Strength of Plastic or reinforced Plastic Pipe by Split disk Method – ASTM D 2290-00 (Published September 2000)	No	Yes	Determines the comparative apparent tensile strength of reinforced thermosetting resin pipe, and thermoplastic pipe.
	ASTM D 2412-96a	Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading – ASTM D 2412-96a (Published November 1977)	No	Yes	Test on thermoplastic resin pipe, reinforced thermosetting resin (RTRP) pipe, and reinforced plastic mortar (RPMP) pipe to determine pipe stiffness, stiffness factor and load at specific deflections.
	ASTM D 2513-01a	ASTM D 2513-01a Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings (8/01)	No	Yes	Included as reference in 49 CFR 192. Specification for polyethylene pipe and fittings that are intended for use in natural gas distribution systems. It does not cover threaded pipe or materials designed for high-pressure use.
	ASTM D 2517-00	ASTM D 2517-00 Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings (7/00)	No	Yes	Included as reference in 49 CFR 192. Specification covers requirements and methods of testing filament wound reinforced epoxy resin pipe and fittings used in natural gas distribution lines.
	ASTM D 2924-01	Standard Test Method for External Pressure Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe – ASTM D 2924-01 (Published August 2001)	No	Yes	Tests on glass-fiber- reinforced thermosetting-resin pipe (RTRP) and glass-fiber-reinforced polymer mortar pipe (RPMP) to determine the resistance of fiberglass pipe to external pressure such as buckling, compression and leaking.
	ASTM D 2992-01	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings – ASTM D 2992-01 (Published August 10, 2001)	No	Yes	Two procedures for obtaining a hydrostatic design basis and a pressure design basis for fiberglass pipe.
	ASTM D 2996-01	ASTM D 2996-01 Standard Specification for Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe" (August 2001)	No	Yes	Classification system, mechanical properties, performance, dimensions methods of testing and marking of thermosetting resin pressure pipe (RTRP) manufactured by the filament winding process up to 24 in. nominal size
	ASTM D 2997-01	ASTM D 2997-01 Standard Specification for Centrifugally Cast "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe (August 2001)	No	Yes	Specifications for machine-made glass-fiber- reinforced thermosetting-resin pressure pipe manufactured by the centrifugal casting process
	ASTM D 3517-01	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe – ASTM D 3517-01 (Published August 2001)	No	Yes	Standard for Water Conveyance at 250 psi or less in fiberglass pipe.
	ASTM D 5685-01	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe Fittings – ASTM D 5685-01 (Published August 2001)	No	Yes	Standards for fittings used with fiberglass pipe. Covers fittings from 1-16 inches and pressures from 25-1000 psig, with specific limitations.
	ASTM D 638-01	Standard Test Method for Tensile Properties of Plastics – ASTM D 638-01 (Published September 2001)	No	Yes	Included as reference in 49 CFR 192 Tests used to determine the tensile properties of both reinforced and unreinforced plastics at standard temperatures, humidity and testing machine speeds.
	ASTM F 1055-98	Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter controlled Polyethylene Pipe and Tubing – ASTM F 1055-98 (Published December 1998)	No	Yes	Included as reference in 49 CFR 192
		American Petroleum Institute (API)			
	API 80	Guidelines for the Definition of Onshore Gas Gathering Lines – API Recommended Practice 80 First Edition, April 2000	Yes	Yes	Defines Gathering lines
	API 1104	Welding of Pipelines and Related Facilities – API Standard 1104 Nineteenth Edition, September 1999	Yes	No	Included as reference in 49 CFR 192
	API 1110	Pressure Testing of Liquid Petroleum Pipelines – API Recommended Practice 1110 Fourth Edition, March 1997	Yes	No	
	API 11B	API 11B for Class "A" Materials (reinforced plastic sucker rod)	No	Yes	Does not address pipe. This standard covers composite materials used in wellbores.

	API 15HR	Specification for High Pressure Fiberglass Line Pipe – API Specification 15HR Third Edition, August 2001	No		Details specifications for fiberglass pipe (RTRP) that can be used in pressure rated systems from 500 psi to 3,000 psi. Pipe included in this specification is limited to that with mechanical connections.
	API 15LE	Specification for Polyethylene Line Pipe (PE) – API Specification 15LE Third Edition, April 1, 1995	No		Standards for the manufacture and testing of polyethylene line pipe and fittings. Polyethylene is commonly used in natural gas distribution systems, running from a trunk line to the customer's meter. References one ANSI specification and 20 ASTM documents
	API 15LR	Specification for Low Pressure Fiberglass Line Pipe – API Specification 15LR (SPEC 15LR) Sixth Edition, September 1, 1990	No		Manufacturing of fiberglass (RTRP) line pipe manufactured by the centrifugally cast (CC) and the filament wound (FW) processes, using thermosetting polymers reinforced with glass fibers.
	API 15TL4	Recommended Practice for Care and Use of Fiberglass Tubulars – AP Recommended Practice 15TL4 Second Edition, March 1999	No		Tubulars in the petroleum industry generally implies pipe or casing used in a well. This API recommended practice not only discusses fiberglass oilfield tubulars, but it also has sections on line pipe (RTRP).
	API 5L	Specification for Line Pipe - API Specification 5L Forty-Second Edition, July 1, 2000	Yes	No	Included as reference in 49 CFR 192 "Specification 5L covers seamless and welded steel line pipe."
	API 5L1	Recommended Practice for Railroad Transportation of Line Pipe, Fourth Edition, 1990			Included as reference in 49 CFR 192
	API 5L2 (RP 5L2)	Recommended Practice for Internal Coating of Line Pipe for Non-Corrosive Gas Transmission Service – API Recommended Practice 5L2 (RP 5L2) Third Edition, May 31, 1987 ANSI/API RP 5L2-87 (Approved 7/12/93)			Application of internal coatings in steel line pipe used in natural gas transportation.
	API 5L7 (RP 5L7)	Recommended Practices for Unprimed Internal Fusion Bonded Epoxy Coating of Line Pipe – API Recommended Practice RP 5L7 (RP 5L7) Second Edition, June 1988	Yes	Yes	Practices for rehabilitating pipelines through the use of epoxy based liner material.
	API 5LC	API SPEC 5LC "Specification for CRA Line Pipe"	Yes	No	
	API 5LCP	API SPEC 5LCP "Coiled Line Pipe"	Yes	No	
	API 5LP	API SPEC 5LP "Specification for Thermoplastic Line Pipe"	No	Yes	Thermoplastic Pipe
	API 6D	API 6D Specification for Pipeline Valves (Gate, Plug, Ball and Check Valves) Twenty First Edition, 1994	Yes		Included as reference in 49 CFR 192
	API 90-60	API Report 90-60 "API Research Report – Project #90-60 Cyclic Pressure Fatigue Evaluation of High Pressure Fiberglass"	No	Yes	Reinforced-Thermosetting-Resin-Pipe (RTRP)
	API 91-70	API Report 91-70 "API Research Report – Project #91-70 Development of Make-up Procedures for Fiberglass Tubing"	No	Yes	Reinforced-Thermosetting-Resin-Pipe (RTRP)
	API CEAC-TR96-0101	API Report CEAC-TR96-0101 "API Research Report – Project CEAC-TR-0101 (93-60) Report #1 of the Final Report Series to API and Amoco – Long Term Leakage Failure of Filament-Wound Fiberglass Composite Laminate Tubing Under Combined Internal Pressure and Axial Loading"	No	Yes	Reinforced-Thermosetting-Resin-Pipe (RTRP)
		American Society of Mechanical Engineers (ASME)			
	ASME / ANSI B16.1	ASME/ANSI B16.1 "Cast Iron Pipe and Flanged Fittings"	Yes		Included as reference in 49 CFR 192
	ASME / ANSI B16.5	ASME/ANSI B16.5 "Pipe Flanges and Flanged Fittings"	Yes		Included as reference in 49 CFR 192
	ASME B31.4	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids - (ASME Code for Pressure Piping, B31.4-1998 Edition)	Yes	Yes Addresses field repairs using composite wrapping	This code applies to Liquid Pipeline Systems, (Oil, LPG) 400.1.2 This code does not apply to (d) casing, tubing, or pipe used in oil wells, wellhead assemblies, oil and gas separators, crude oil production tanks, other producing facilities and pipelines interconnecting these facilities, (f) gas transmission and distribution piping
	ASME B31.4a-2001	ASME B31.4a-2001 Addenda to Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids (Addendum to B31.4-1998)	Yes	Yes, addresses field repairs using composite wrapping	This ASME code applies to hydrocarbons, liquid petroleum gas (LPG), carbon dioxide and other liquids. It does not directly apply to natural gas but is listed here to clarify that it addresses LPG.

	ASME B31.8	Gas Transmission And Distribution Piping Systems - ASME Code For Pressure Piping B31.8-1999 Edition (Revision of ASME B31.8-1995)	Yes	Yes	Included as reference in 49 CFR 192 This ASME code applies to the design, fabrication, installation, inspection, and testing of pipeline facilities used for transportation of natural gas. It does not apply to flowlines or LNG piping systems. This code addresses plastic pipe and divides it into two general types; Thermoplastic, which is a plastic that is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature, Thermosetting plastic which is plastic that is capable of being changed into a substantially infusible or insoluble product when cured under application of heat or chemical means.
	ASME / ANSI B31G	ASME/ANSI B31G "Manual for Determining the Remaining Strength of Corroded Pipelines"	Yes	No	Included as reference in 49 CFR 192
		ASME Boiler and Pressure Vessel Code, Section I "Power Boilers"			Included as reference in 49 CFR 192
		ASME Boiler and Pressure Vessel Code, Section VII, Division 1 "Pressure Vessels"			Included as reference in 49 CFR 192
		ASME Boiler and Pressure Vessel Code, Section VII, Division 2 "Pressure Vessels Alternative Rules"			Included as reference in 49 CFR 192
		ASME Boiler and Pressure Vessel Code, Section IX "Welding and Brazing Qualifications"			Included as reference in 49 CFR 192
		American National Standards Institute (ANSI)			
		ANSI B31.4 Liquid Petroleum Transportation Piping Systems (1979)	Yes	No	This standard is for LPG
		Others			
	NFPA 58	Liquefied Petroleum Gas Cod- NFPA 58 2001 Edition (National Fire Protection Association)	Yes		
		Oil Pollution Act of 1990 (Public Law 101-380)	Yes	Yes	
		49 U.S.C. 60101 et Seq.	Yes	Yes	The Pipeline safety laws in the U.S. Code
		49 U.S.C 5101 et seq.	Yes	Yes	The Hazardous Materials Transportation laws in the U.S.Code
		American Water Works Association D120-84 (R89) 1st Edition AWWA Standard for Thermosetting Fiberglass-Reinforced Plastic Tanks	No	Yes	
		NACE Standards RP-01-69 Corrosion	Yes	No	
		MSS SP-44-96 "Steel Pipe Flanges"	Yes	No	Included as reference in 49 CFR 192
		All Types of Pipe			
		Steel Pipe			
		Thermoplastic / Polyethylene, RTRP			

Appendix E

Research Topics and Sources of Further Research Information

Appendix E Research Topics and Sources of Further Research Information

This appendix contains three major groups of composite materials information. First, it has brief descriptions of recent or ongoing composite research. Then a list of composite related websites is provided. Following that a list of selected journals with composite research or topics is provided. Finally, a partial list of universities with composite research programs is provided.

I. Recent or Ongoing Composite Research

Large Diameter Reinforced Thermoplastic Pipe
Composites Group - Applied Mechanics & Polymer Engineering
Department of Mechanical Engineering University of Twente Enschede the Netherlands
Start 6/1/01   Finish 3/31/04 Partners: Pipelife NL, Seaflex AS, Sulzer Innotec
Reinforced Thermoplastic Pipes offer flexibility, good fatigue and corrosion resistance combined with a low weight while permitting efficient continuous production methods. Although the material costs exceed those of conventional steel pipe systems, the total life cycle costs of RTP's compare favorably when other operational costs such as installation and repair are considered. This project aims to develop a pipe with a high pressure and temperature resistance and a high resistance to very unfavorable environmental circumstances and aggressive chemicals. Furthermore, the pipe system must be flexible enough to allow for a relatively easy and low-cost subsea installation technique.
http://www.composites.ctw.utwente.nl/PROJECTS/index.shtml#ldrtp

Composite-to-Metal Joints
University of Cambridge Composites and Coatings Group
Polymer composite materials (PMCs) are gradually replacing metallic components in applications where there is a cost or performance advantage to be gained. However metallic components are still more suited to some applications than PMCs often creating the need to reliably join metals and PMCs. This project focuses on two examples of this, a glass fibre composite to steel joint for use in naval vessels and a carbon fibre composite to titanium joint for use in formula one racing cars.
http://www.msm.cam.ac.uk/mmc/

Composite Materials Research
University of Delaware Center for Composite Materials - Research Areas 1998-1999
The focus of the materials and synthesis area is on the creation and tailoring of materials through control of microstructure and molecular architecture. An important component of the work is to identify microstructural changes and molecular organization. Tailoring at the microstructural level can be accomplished through control of processing conditions, while molecular-level tailoring requires new syntheses and combinations of materials. The mechanics and design area focuses on relating the microstructure and internal architecture of composite materials to their performance. The emphasis is on understanding how the control and design of microstructure can improve mechanical performance. This area provides a vital link from the materials and synthesis area to processing science and performance, as the selection of materials and processing conditions can establish the characteristic microstructure, which is linked directly to performance. Under the processing science area, Center research focuses the development of process models and simulations in a "virtual manufacturing" environment. A full complement of composites fabrication facilities is available for lab-scale validation of the research, with

capabilities including autoclave molding, compression molding, RTM and VARTM, filament winding, fiber placement, microwave curing and joining, electron beam cure, and induction curing and bonding. A unique aspect of CCM's research in this area is the investigation of novel processing techniques. http://www.ccm.udel.edu/publications/AR/overview.html

Damage, Fracture, and Failure of Composite Structures (web site update in 1998)
University of British Columbia, Vancouver, Canada
Our concern with damage, fracture and failure of composite structures is currently focused on understanding basic physical mechanisms of delamination, matrix cracking, and general damage growth. The two current active areas are delamination growth and a strain-softening approach to damage growth.

Delamination Behavior
A technique has been developed for measuring the local crack tip displacement fields and the global applied parameters during mode I, mode II, and mixed-mode loading of delaminations in composite laminates up to and including failure. To achieve this objective, an instrumented loading set-up has been designed to fit inside the chamber of a scanning electron microscope (SEM).

With this technique, the SEM images of loaded specimens are analyzed to obtain the crack opening and shear displacements as a function of distance from the crack.

The motivation for this work is that typical composite structures have complex geometries and carry complex loadings. As seen in the figure below, the range of scales of interest is very large.

However, there is currently considerable controversy about the exact nature of mixed-mode fracture behavior. Typically, it is determined from simple geometry specimens such as the double cantilever beam (DCB), the end notch flexure (ENF), and the mixed-mode bending (MMB) specimens where the strain energy release rate is calculated from the global applied loads and geometry using Linear Elastic Fracture Mechanics (LEFM) to represent crack tip behavior. Although this approach has been well developed and proven for homogeneous isotropic materials, some issues are raised when applied to composites laminates. Local perturbations such as resin rich region, fibre bridging, crack path wandering and friction have been noticed by investigators. Thus global applied loads are perhaps not transposed directly into equivalent local crack tip conditions. http://www.composites.ubc.ca/research/damage.asp

Impact and Ballistics of Composite Structures
University of British Columbia, Vancouver, Canada
Over the past six years, our research group has been very active in the development of analytical and numerical models for predicting the impact response of laminated composite structures with varying levels of complexity, and more recently, for predicting the impact response of textile armor systems. In particular, two distinct modeling approaches have been undertaken: analytical and numerical. In all cases, our modeling is supported by significant experimental activity: damage mechanism identification to ensure the physical validity of our models, materials characterization to provide inputs into our models, and ballistic and structural response validation to confirm the accuracy and usefulness of our models. http://www.composites.ubc.ca/research/impact.asp

Cure Cycle Optimization For The Fabrication Of Thermosetting-Matrix Composites
University of Connecticut NEERAJ RAI M.S. in Mechanical Engineering, February 1997
Polymer-matrix composites using thermosetting resins as the matrix are increasingly finding use in several applications. However, a major impediment to their widespread commercial use is the high cost associated with their manufacture, arising from the long processing cycle times. This study addresses the problem of determining cure temperature and pressure variations with time (referred to as the *cure cycles*) for a time-optimal fabrication of thermosetting-matrix composites subject to practical constraints. The

optimal cure cycles are determined using a nonlinear programming scheme combined with experimentally-validated numerical models to simulate the physical process phenomena.

The numerical process models used in the above-mentioned approach are often computationally intensive, and the computational burden is further increased as a result of the iterative invocation of the models during the optimization process. Towards alleviating the computational tedium, the study also presents the use of artificial neural networks trained using the physical process models as a practical substitute for rigorous numerical simulations in the process optimization endeavor in particular, and simulation-assisted materials manufacturing, in general. http://www.eng2.uconn.edu/cml/research.htm

Virginia Tech Center for Composite Materials and Structures
Report Series Year 2001
Xiaolan Song and Alfred C. Loos, "Modeling of Thermoplastic Composite Filament Winding"
http://www.research.vt.edu/ccms/reportseries2001.html

Virginia Tech Center for Composite Materials and Structures
Report Series Year 1999
Schultz, M. R., and M. W. Hyer, "Energy Absorption Capacity of Graphite-Epoxy Composite Tubes"
http://www.research.vt.edu/ccms/reportseries2001.html

Berkley Composites Laboratory – University of California
Craze/void nucleation and growth kinetics in thermoplastics and thermosets. Specimens of linearly varying cross-sections are subjected to creep loads to nucleate crazing or voids. Lateral slices of the specimens are polished and studied for defect size and microstructural features. Temperature dependence will be determined. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
High pressure storage tanks. Lined tanks reinforced with carbon fiber prepreg is a possibly attractive process for lowering the cost of compressed natural gas tanks. Design using finite-element analysis will be followed by scale-model (half-scale) construction and evaluation. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Local reinforcing with carbon composites and its effect of fatigue crack propagation. Aluminum fracture specimens will be precracked in cyclic loading and then "repaired" with composite patch reinforcements. The effect of such reinforcements on suppressing crack propagation will be determined and a theory developed. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Pin bearing strength in glass composites. Pin bearing strength and the associated failure modes will be studied and a theory developed. Cyclic loading will be evaluated. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Machinery for low-cost composite fabrication. Study existing machinery used in the manufacture of underground gasoline tanks and sewer pipes with a view to modifying them for other types of structures.
http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Carbon-carbon composites properties. Determine properties and study new applications for carbon-carbon composite materials. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California

Erosive and abrasive wear. Copious data on wear behavior of composites exist; however, there is no good theory for the wear behavior of these materials that fully take into account the wear behavior of the constituents and the fiber-matrix interfacial strength. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Crack tip plasticity in functionally gradient materials. Crack propagation in materials is a function of the formation and growth of a "plastic" zone at the tip of the crack. Does this have validity in a composite material in which the reinforcement volume fraction is varying? http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Design of functionally gradient materials. Design approaches for specifying the volume fraction gradient and the type of reinforcement required for various applications, such as piping with internal pressure and thermal gradients, are not presently available. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Hard coating design for contact stress applications. Composites perform poorly when subjected to rolling contact stresses. There has been no systematic study of the mechanisms of failure, and the requirements for coatings that can reduce surface damage. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Ablative matrix composites. Such materials have been used in early re-entry space vehicles. Terrestrial uses include light-weight fire-resistance walls in ships and aircraft where compressive strength retention is vital. http://bcl.me.berkeley.edu

Berkley Composites Laboratory – University of California
Stress relaxation in composite bolted joints. Polymer matrix composites creep under thickness-direction compressive loading resulting in loosening of the bolted joint and subsequent fatigue failure. Stress relaxation laws will be postulated as a function of fiber type, fiber volume fraction and matrix characteristics. http://bcl.me.berkeley.edu

Composite Manufacturing NDE Using Active Infrared Thermography
R. B. Dinwiddie and B. J. Frame
The Oak Ridge National Laboratory (ORNL) has successfully demonstrated using internal R&D funding the application of active infrared (IR) thermography as a viable NDE technique for detecting porosity, resin starvation, and other flaws in uncured composites. The advantage of active thermography for this application is that it is completely non-contacting, using remote heating and remote detection to make the measurements. Dynamic measurements made as part of this research indicate that the technology has potential for deployment as a QA tool in continuous manufacturing processes such as pultrusion and filament winding. Although other NDE technologies currently exist for detecting large areas of porosity, resin starvation and other flaws in composite structures, these methods rely on the composite first being cured prior to inspection. The manufacturer must therefore complete the fabrication and incur the costs associated with cure, tooling removal and handling before a determination of the composite's quality can be made. At that point, corrections to the process can only be made for subsequent fabrications while the defective composite hardware is scrapped. By detecting flaws prior to the costly and time consuming curing step, active IR thermography can provide a great benefit to the composite manufacturing industry.
http://www.ms.ornl.gov/researchgroups/composites/pmc.htm

"Durability of Marine Composites" by Paul H. Miller
Berkley Composites Laboratory – University of California Currently active research 2002

By comparing the standard industry test methods and an improved test method against full-size results, an improved design procedure can be used to reduce the required factors of safety in marine composites design.

Composite materials are used throughout the marine industry for numerous applications including primary and secondary structure, superstructures, piping, shafts, foundations, ducts, and gratings. Most applications are in small commercial vessels and recreational craft, with composites use in offshore structures rapidly growing. One estimate is that 20-30% of new marine applications are made of composite materials.

The history of composites in the marine environment is about 35 years old. During this time few documented examples of fatigue failure have occurred. One reason for this is the large factors-of-safety, ranging from 2-4, that are used with conservative design rules. The primary reason for these factors-of-safety is the uncertainty in the material properties, and in particular, the long-term properties. Very little data is available on long-term, in-service effects, which drives the engineer to choose conservative values. This problem is a significant obstacle to the efficient use of marine composite structures. The conclusions from a National Research Council Workshop in 1990 (Use of Composite Materials in Load-Bearing Marine Structures) support the belief that long term properties need further research. The committee, comprised of academic and industrial leaders in marine and aerospace applications identified four key design areas in marine composites requiring development. These were:

- Characterizing the current analysis methods and end-users of marine composites.
- Thick (>0.25") composites properties and analysis methods.
- Manufacturing technologies for thick composites.
- Design procedures to achieve durability and reliability.

Since then, almost all marine composites research has focused on thick composites analysis and manufacturing. This project focuses on design procedures for durability and reliability.
The research specifically addresses two large uncertainties in the reliability analysis of marine composites: "Are the standardized tests used to develop the material properties for design purposes accurately reflecting the actual material properties?" "Do the analysis methods currently used accurately model reality?" Sponsors include: American Bureau of Shipping, TPI, J-Boats, OCSC, Maricomp
http://bcl.me.berkeley.edu

Van Paepegem, W., Degrieck, J., Coupled Residual Stiffness and Strength Model For Fatigue of Fibre-Reinforced Composite Materials. Composite Science and Technology v. 62 No. 5 2002, pp 687-696

Schieffer, Anne, Jean-Francois, Marie, Leveque, D., A Coupled Analysis of Mechanical Behavior and Ageing For Polymer-Matrix Composites, Composites Science and Technology v. 62 No. 4 2002, pp 543-549

Jacquemin, F., Vautrin, A., The Effect of Cyclic Hygrothermal Conditions on the Stress Near the Surface of a Thick Composite Pipe, Composites Science and Technology v. 62 No. 4 2002, pp 567-570

Seth S. Kessler, S. Mark Spearing, Mauro J. Atalla, Carlos E.S. Cesnik, Constantinos Soutis, Damage detection in composite materials using frequency response methods, Composites Part B: Engineering v. 33, No. 1 2002, pp 87-95

Kwang-Hee Im, Cheon-Seok Cha, Sun-Kyu Kim, In-Young Yang, Effects of temperature on impact damages in CFRP composite laminates, Composites Part B: Engineering, v. 32, No. 8 2001, pp 87-95

W. Van Paepegem, J. Degrieck, P. De Baets, Finite element approach for modeling fatigue damage in fibre-reinforced composite materials, Composites Part B: Engineering, v. 32, No. 7, 2001, pp 575-588

T.C. Kennedy, M.H. Cho, M.E. Kassner, Predicting failure of composite structures containing cracks, Composites Part A: Applied Science and Manufacturing, v. 33, No. 4, 2002, pp 583-588

Gas Research Institute

In a 1999 article on Researching Real-Time Pipeline Monitoring, Harvey Haines a program manager for the Gas Research Institute estimated that pipeline companies spend about $100 million a year replacing pipe as a result of regulations requiring pipe upgrades as urban development encroaches on existing pipelines.[16] The Gas Research Institute has funded a number of investigations that looked at the natural gas pipeline industry. The reports are available for purchase, with a summary available on the internet. The limited scope for this project did not allow purchasing of these reports, but the summaries are provided for addition information on some of the research conducted in the past few years.

A May 1999 GRI report discusses new high strength steels and engineered composites that will leak before rupturing. These materials also have the potential for higher operating pressures and larger diameters. The report discusses composite reinforced line pipe (CRLP) and future research and development in safe pipe design. [17]

Each year there are conferences and other forums where interested natural gas pipeline companies gather to addressed the issues and future needs facing the industry. Safety is always the top priority, followed by reliability and efficiency. Issues that come up over and over again include;

- Optimizing pipeline capacity. The environmental and regulatory certification hurdles and the cost of acquiring new right of way and laying new pipelines dictate that optimum throughput be attained. This leads to discussions on larger diameter, higher pressure pipelines.
- Advance materials and methods for pipeline repair
- Advanced materials and methods for rehabilitation of existing aging pipelines, (liners, coatings – internal and external), for high and low pressure lines, especially distribution lines in urban areas were trenching is expensive and very disruptive.
- Advanced methods to warn potential construction operations of the presence of buried gas lines. Old Polyethylene pipe. New methods can put tracers in the lines as they are formed.
- Advanced methods to determine stress and strain due to environmental/natural causes prior to pipe failure
- Reduce the cost of operating and maintaining existing gas distribution systems
- Armoring above ground natural gas pipeline segments
- Better pipe joining technology for both PE distribution pipelines and high-pressure steel and composite lines
- Utilities in the local distribution business are facing increasing tough economic conditions with the increase in compliance costs for local, state and federal regulations, tougher permit requirements, higher fees for making utility cuts in streets. Aside from the municipal fees, estimates of the cost of excavation and ground or pavement reinstatement indicate that it can be up to 70 percent of the cost of any gas construction project. At the same time the price of natural gas has not changed

significantly over the last 20 years and the competitive natural gas market is expected to keep prices very competitive and low for the foreseeable future.

II. Composite Related Websites

Composite Fabricators Association http://www.cfa-hq.org/index.html

Worldwide Composites Search Engine
Search engine that covers composite related organizations and products. Has discussion groups, and a database for sale of surplus composites materials. http://www.wwcomposites.com/

Composites Materials Guide – a guide from minigco.com A guide of composite related information ranging from organizations, materials, manufacturing etc. http://composite.miningco.com/

Lawrence Livermore National Laboratory Manufacturing and Materials Engineering Division (MMED)
http://www-eng.llnl.gov/eng_llnl/01_html/eng_mmed.html

Composite Materials Technology Group – Oak Ridge National Laboratory
Resource that performs R&D of composite material applications and manufacturing technology.
http://www.ms.ornl.gov/researchgroups/composites/pmc.htm

Fiberglass World – site for promoting trade in the fiberglass industry. http://www.fiberglass.com/

III. Selected Journals with Composite Topics

These are a sampling of some of the journals, magazines and other publications that publish information in the composite materials field and have online archives listing their content. The web links are through Elsevier Science. The following website will take you to a menu on one of the Elsevier Science web pages that covers all types of composites.
http://www.elsevier.nl/inca/tree/?mode=advanced&key=G09607&sarea=sai

Composite Structures
Design, R&D, experimental investigations, analysis and fabrication techniques for the use of composites in load-bearing components. 1995 to previous year. Elsevier.

Composites Part A: Applied Science and Manufacturing
Properties, design, and manufacturing. "High-tech" composites, cements, woods, and others. Economic and commercial articles welcome. 1995 to previous year. Elsevier.

Composites Part B: Engineering
Original research on all aspects of composites, with an emphasis on evaluation and modeling of engineering details and concepts. 1994 to 1996. Elsevier.

Composites Science and Technology
Fundamental and applied science of composites. "High-tech" composites, cements, and woods, and others. Balanced experimental and analytical. 1995 to previous year. Elsevier.

Composites Technology
Trade magazine with an emphasis on civil, architectural, and industrial applications. 1995 to previous year. Current month summary also available. Ray Publishing.

Experimental Mechanics
Quarterly journal published by SEM. Covers the experimental characterization of materials. Most issues have some composite articles. Contents back to 1997.

High-Performance Composites
Trade magazine with an emphasis on the aerospace industry and other high-tech uses. 1993 to previous year. Current month summary also available. Ray Publishing.

JOM
Monthly journal published by TMS covering materials science and engineering. Hardcopy or full text PDF articles available for purchase. Full contents back to 1994.

Journal of Advanced Materials
Quarterly composites publication from SAMPE. Unlike the SAMPE Journal, this JAM has peer-reviewed technical papers. Titles and abstracts from 1996 to present.

Journal of Composite Materials
Theoretical and experimental findings on physical and structural properties. Fracture, fatigue, structural reliability, and design criteria are given special attention. Contents from January 1996. Technomic.

Journal of Intelligent Materials Systems and Structures
Smart materials and structures. with an emphasis on the science of active materials. Last two years. Technomic.

Journal of Matls Processing and Mfg Science
New developments and fundamental studies of transport phenomena in processing, experimental methodology, and computational analysis. 1996. Technomic

Journal of Reinforced Plastics and Composites
Materials, properties and performance, design, characterization and analysis, and computer assistance. Last year. Technomic.

Journal of Vinyl & Additive Technology
SPE journal for new work in polymer modifiers and additives. Browse titles by year and month; view full abstracts. Full text articles available to subscribers or for fee.

Mechanics of Composite Materials
English translation of Russian publication. Highly theoretical. Full contents back to March-April 1995. Titles and authors only; no abstracts.

Polymer Composites
SPE journal covering applied , pre-commercial developments. Browse titles by year and month; view full abstracts. Full text articles available to subscribers or for fee.

Polymer Engineering & Science
SPE journal for researchers and chemists in polymers and plastics. Browse titles by year and month; view full abstracts. Full text articles available to subscribers or for fee.

Reinforced Plastics
Worldwide composites industry. New products, production technologies, innovative applications of reinforced plastics and business moves. 1997 to present. Elsevier.

IV. Selected Universities with Composite Research Programs

University of Bristol – Composites and Adhesives Group
http://www.men.bris.ac.uk/emrc/compad.html
Research group with an emphasis on FRP and mechanical testing, including adhesive joints, environmental effects, custom test-rigs, and laser and optical measurement.

University of Delaware – Center for Composite Materials http://www.ccm.udel.edu
One of the leading academic research centers, active in all area of composites research. Extensive site with Center information, composite, student and faculty resources, plus interactive software.

University of Newcastle upon Tyne – Centre for Composite Materials Engineering
http://www.ncl.ac.uk/ccme/ Recent research include pultrusion of thermoplastic composites and flow behavior of glass mat TPs. Site also has information on University of Newcastle conferences.

The University of Nottingham – Polymer Composites Group
http://www.nottingham.ac.uk/%7Eeazwww/composite/index.html The composites group operates within the School of Mechanical, Materials, Manufacturing Engineering and Management and focuses on the processing and performance of polymer matrix composites. We have interests in both thermoset and thermoplastic matrices.

University of Connecticut – Composites Processing Laboratory *http://www.eng2.uconn.edu/cml/*
Manufacturing science of composite materials including understanding the complex materials microstructures and physical phenomena governing their fabrication.

University of Southern California – Composites Center
http://www.usc.edu/dept/materials_science/ccr/
Involved in a wide variety of composites research.

University of Twente Department of Mechanical Engineering Section of Applied Mechanics and Polymer Engineering – Composites Group http://www.composites.ctw.utwente.nl/
The aims of the group are to conduct research into the mechanisms and modeling of deformation and failure of continuous fibre composites under different rates of loading. Research in the Composites Group is concerned with the cost-effective application of advanced composite materials.

University of Cambridge - Department of Materials Science and Metallurgy, Composites and Coatings Group http://www.msm.cam.ac.uk/mmc/
Research areas include composite to metal joints, surface coatings, laser drilling, metal / ceramic composites, plasma spraying, and processing. Lists of members, projects, publications, facilities.

University of California at Berkley – Berkley Composites Laboratory http://bcl.me.berkeley.edu
Develop solutions to engineering problems through the use of advanced materials and creative design approaches. Conduct research on behavior of materials, structures and mechanical systems. Develop low-cost process techniques for advanced materials.

University of Sidney, Australia – Centre for Advanced Materials Technology (CAMT)
http://www.camt.usyd.edu.au/
Interdisciplinary materials research group. Site lists people, lab facilities, research projects, grants and contracts.

Katholieke Universiteit Leuven, Belgium - Division PMA of the Katholieke Universiteit Leuven (KUL) is involved in a diverse range of research activities. Design of lightweight structures focuses on filament wound and pultruded composites, plus deep drawn textile composites.

Michigan State University Composite Material & Structures Center -
http://www.egr.msu.edu/cmsc/
Interdisciplinary lab mainly optimization of processing and fabrication, but with research in many areas. Large site: research and staff profiles, newsletters, and facilities list.

Northwestern University, Evanston, IL – Composite Materials at Northwestern University
http://qefp486.cqe.nwu.edu/
This Northwestern University lab covers a variety of research topics. Brief research overviews, publications list, and list of grants and contracts. See also the Center for Intelligent Processing of Composites at Northwestern University http://www.mech.nwu.edu/dept/research/index.html

Princeton University – Princeton Complex Materials Theory Group
http://cherrypit.princeton.edu
Studies the relationship between the macroscopic behavior of complex materials and their microstructures. Research abstracts, staff list, and publications list. Other sites with composite research at Princeton University include, Princeton Center for Complex Materials

http://www.princeton.edu/%7Epccm/ and Princeton Materials Institute
http://www.princeton.edu/%7Epmi/index2.htm

Rensselaer Polytechnic Institute – Center for Composite Materials and Structures
http://www.rpi.edu/dept/research/centers/ccms.html
Coordinates composites activities among Civil, Materials, Mechanical Engineering, and Chemistry departments. Research in all aspects of composites.

Delft University of Technology – Structures & Materials Laboratory
http://www.sml.lr.tudelft.nl/research/index.html
An interdisciplinary group involved in the design, analysis and production of products made from composites, metals and hybrid materials. Extensive site with info about students, faculty, publications and industry partnerships.

University of Maryland College Park – Composites Research Lab
http://www.core.umd.edu
Research laboratory at the College Park Campus. Site includes mission statement, list of publications, list of personnel, and a facilities description. Part of the Aerospace Engineering Program.

University of British Columbia – Composites Group http://www.composites.ubc.ca/research/
The Composites Group is an interdisciplinary research group spanning the two departments of Metals and Materials Engineering and Civil Engineering at UBC. The group conducts applied and fundamental research in many areas dealing with advanced composite materials and structures, including impact, processing and fracture. Major research funding in the form of contracts and grants is provided by industrial and governmental agencies, e.g. The Boeing Company (Seattle), SNC (Montreal), Canadian Department of National Defense, NSERC.

University of Wyoming – Composite Materials Research Group http://wwweng.uwyo.edu/cmrg/
The emphasis of the Group has always been on producing high quality technical data for a growing composite materials industry. The CMRG's testing capabilities are extensive. In addition to three Instron and MTS universal test frames with load capacities ranging from 1N to 100,000 pounds, many special facilities exist for creep testing, biaxial testing, and fatigue. An expert staff is available to design test programs for a wide variety of applications.

Virginia Tech -The Center for Composite Materials and Structures (CCMS)
http://www.research.vt.edu/industry/areas/advancedmats.html
CCMS is an interdisciplinary center designed to coordinate research and education in composites processing, materials, structures, and properties at Virginia Tech. The present thrust is aimed at composites processing with an emphasis on increasing processing rates. CCMS is the convening organization for the composites community at Virginia Tech. It receives more than $8 million annually for research and has been rated the number one university program in the country in terms of size and breadth of its composite activity - presently more than 90 projects. CCMS sponsors publications and short courses on subjects ranging from polymer synthesis to manufacturing and processing, durability and damage tolerance, and adhesion science and engineering.

Wichita State University – Composites and Advanced Materials Laboratory
http://www.niar.twsu.edu/home.asp?targ=overview
National Institute for Aviation Research (NIAR), Wichita State University. The composites laboratory specializes in developing low cost manufacturing processes while providing thermal, mechanical and analysis tools necessary for a fully integrated project. The lab also provides hands-on training workshops in composites topics and supports academic programs in the College of Engineering.